FEBRUARY 1976

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ACN 21646

TR 4-76

AD A024167

TETAM MODEL VERIFICATION STUDY

Volume I

REPRESENTATION OF INTERVISIBILITY INITIAL COMPARISONS

Technical Report TR 4-76

UNITED STATES ARMY COMBINED ARMS CENTER

COMBINED ARMS
COMBAT DEVELOPMENTS ACTIVITY

Combat Operations Analysis Directorate

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Technical Report 4-76
February 1976

Directorate of Combat Operations Analysis
US Army Combined Arms Combat Developments Activity
Fort Leavenworth, Kansas 66027

TETAM MODEL VERIFICATION STUDY

Volume I

Representation of Intervisibility, Initial Comparisons

by

MAJ Allan R. Christensen
MAJ John R. Statz, Jr.
CPT David K. Hugus
Mr. Roger L. Burroughs
Mr. James F. Fox
Mr. John E. Gahan
Mr. Ross A. Wells

ACN 21646

Approved by:

David J. Farmer
David J. Farmer
Chief, Model Support Division

Leland C. Pleger
Leland C. Pleger
Technical Director

Reed E. Davis, Jr.
Reed E. Davis, Jr.
Colonel, IN
Director

ABSTRACT

The TETAM Model Verification study is reported in three volumes describing the validation of three high resolution combat simulation models (DYNTACS, IUA, and CARMONETTE) using field data collected by US Army Combat Developments Experimentation Command during Experiment 11.8. Volumes I and II contain an intervisibility study describing the abilities of the DYNTACS, IUA, and CARMONETTE terrain processors to predict line-of-sight occurrences between tanks and antitank missile positions. Volume III contains a validation study of the engagement processors of DYNTACS and IUA. The results from the simulation models in terms of firings, engagements, and losses between tank and antitank as compared with the field data collected during the free play battles of Field Experiment 11.8 are found in Volume III.

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EXECUTIVE SUMMARY

1. INTRODUCTION. The Tactical Effectiveness Testing of Antitank Missiles (TETAM) program, originated in December 1970 by Department of Defense Program Budget Decision 464, consists of three major elements: a field experiment conducted by Combat Developments Experimentation Command (CDEC) in 1972-73, a detailed evaluation of the effectiveness of US antitank missile weapons based primarily upon data collected during the field experiment, and an evaluation of the predictive abilities of three of the Army's frequently used high resolution simulation models of tank-antitank warfare using the results of the field experiment as a baseline. Progress on this third major element of the TETAM program, the Model Verification Study, is the subject of this report.

2. PURPOSE. The purpose of the Model Verification Study is to determine the ability of the DYNTACS, CARMONETTE, and Individual Unit Action (IUA) high resolution combat simulations to:

a. Predict the outcomes of selected tank-antitank battles conducted (simulated) during the CDEC Experiment 11.8.

b. Represent the major battlefield activities and processes leading to these outcomes.

3. SEQUENTIAL STUDY. Each of the three models is designed to simulate the conduct of tank-antitank battles by playing in detail the fundamental battlefield activities of participating personnel and weapon systems and the environment within which these activities occur. These fundamental activities include but are not limited to the search for, detection, recognition, and identification of targets on the battlefield; the loading, laying, and firing of antitank weapons; and the process of guiding antitank missiles on their intended targets. For any given weapon crew, these activities often occur in well defined sequences. Within a given sequence, the occurrence of one activity is normally dependent upon the previous occurrence of the preceding activities; and most of these fundamental activities are either directly or indirectly conditional upon the existence of line of sight (intervisibility). A sequential approach to the study was appropriate, and a comprehensive evaluation of each model's ability to represent accurately intervisibility between attacker and defender elements on the battlefield was determined to be a necessary first step in this sequence.

4. OBJECTIVE. The specific objective of the intervisibility study was to determine whether the three models provide an accurate representation of intervisibility between attacking armored elements and defending antitank missile systems.

5. CONCEPT. The concept for accomplishing the intervisibility study was founded on three salient features.

a. The field experiment is the baseline against which model performance is evaluated. Thus, the models are set up and run under conditions as close as possible to those of the field experiment; and results from the models are compared to those of the field experiment.

b. Comparisons of model and field experiment results are made in terms of fundamental variables rather than aggregated or abstracted measures wherever possible.

c. As outlined above, model verification is accomplished through an orderly and sequential process so that causes of differences between models and the field experiment can be isolated, identified, and, if appropriate, resolved.

6. FIELD EXPERIMENT DATA. One of the objectives of CDEC Experiment 11.8 was to collect data suitable for use in model verification.

a. Phase I, CDEC Experiment 11.8, conducted March through December 1972, collected data on the frequency and duration of intervisibility between defensively emplaced antitank missile weapons and advancing enemy armored vehicles for 12 sites in West Germany, 2 sites at Fort Lewis, Washington, and 2 sites at Hunter-Liggett Military Reservation, California. Thus, a considerable amount of detailed intervisibility data were available from the field experiment for use as a standard against which to evaluate model performance.

b. The intervisibility data collected at Hunter-Liggett were selected for use in evaluating model performance because all data other than the intervisibility data produced by Experiment 11.8 were collected only on the Hunter-Liggett experimentation sites. These Hunter-Liggett intervisibility data were collected during September and October 1972 on two partially overlapping 2x5 kilometer terrain sites, the characteristics of which were distinctly different. Thus, Hunter-Liggett field data were available for an evaluation of model performance in two diverse terrain environments. Two sets of data for different sets of approach routes were collected on one of these sites, thus providing three sets of intervisibility data for comparisons.

7. MODEL PREPARATION AND OPERATION.

a. Preparation. As the data collected during the intervisibility field experiment provided the baseline against which model performance was to be evaluated, it was necessary to reproduce in the models conditions as close as possible to those of the field experiment. Thus, the design and conduct of the intervisibility field experiment provided the foundation upon which the model preparation work was based. Specific policies governing model preparation were designed to produce (1) intervisibility data for conditions similar to those of the field experiment, and (2) model results that could be considered generally representative of model capabilities in typical applications. The DYNTACS(X) and IUA

models were prepared and operated by members of the study team at CACDA. Preparation and operation of the CARMONETTE VI model was accomplished at Concepts Analysis Agency under direction provided by the CACDA study team.

b. Operation. A plan for running the three models was developed calling for three basic runs of each model, one for each of the three field trails that produced the Hunter-Liggett intervisibility data. These model runs were performed, and model results were compared to corresponding results from the field experiment. Several supplementary runs were also made in an effort to investigate specific questions related to unique design features of the DYNTACS and IUA models. These basic and supplementary model runs provided the data necessary for evaluating model performance.

8. ANALYSIS OF RESULTS. Model performance was evaluated in three different ways. First, several different methods were used to compare field experiment results to the results produced by each model. Additionally, the results produced by each model were compared to those from each of the other two models. Finally, a limited amount of sensitivity testing of the models was undertaken in an effort to provide insights into model validity.

9. PRINCIPAL FINDINGS AND INTERPRETATION.

a. The various model and field data comparisons provided the following findings:

(1) Model and field results were markedly different for all three sets of field conditions. The models exhibited a general tendency to depict the sites studied as being more favorable to target acquisition and engagement than was reported in the field experiment.

(2) In one case (IUA in the more cluttered terrain site), model performance was highly erratic and exhibited no decipherable pattern of disagreement with field results. In the other cases, several general trends were observed:

(a) For a given defender position and 500-meter portion of an attacker approach route, the models tended either to agree closely or to disagree widely with field results. The two cases appear equally likely, each occurring about 40 percent of the time.

(b) The model and field data agreement areas are likely to be areas where the field data indicate that either none or nearly all of an approach route segment can be seen from the defender positions.

(c) In areas of disagreement, the models tend to indicate more intervisibility than was recorded in the field.

(d) The models indicate that changes in weapon height have a much more pronounced effect on intervisibility levels than is indicated in the field data.

(3) Although similarities exist, serious differences among the models are obvious.

b. Review of the experimental procedures leads to some questions as to the quality of the experimental data. This, in turn, limits the ability to interpret the findings cited above. Even taking into consideration the possible limitations of the experimental data, the extent of model and field disagreement, when combined with the disagreement among models themselves, must indicate a serious model problem. The specific source of the problem, however, is not known; and the models and model data, field experiment data, and comparison approach followed are all potentially contributing. Thus, further study to define more clearly and rectify the problem appears indicated.

10. CONCLUSIONS.

a. Major differences exist between intervisibility levels and patterns produced by the three combat models and those recorded in the intervisibility field experiment.

b. The general lack of close agreement between results from any two models indicates diverse model problems.

c. In light of the magnitude of differences observed, it is clear that these differences must be resolved before proceeding to investigation of model representation of battlefield activities that are contingent upon intervisibility.

11. FOLLOW-ON ACTIONS. The findings of the original intervisibility comparisons led to additional work in the area oriented toward explaining the observed model and field differences and correcting model deficiencies, at least to a sufficient degree to permit reasonable investigation of other intervisibility-dependent battlefield activities. The follow-on work is reported in Volume II of the TETAM Model Verification Study Report.

12. SUMMARY. The first phase of model verification, the initial evaluation of the models' ability to represent accurately intervisibility between attacking and defending ground weapons, has been completed. Because several concerns related to the reliability of field experiment data were identified, study findings and conclusions must be considered tentative until each of these concerns is investigated. However, study results generally substantiate widely held concerns regarding the reliability of results produced by high resolution models of combat and indicate that continued emphasis in the field of model validation is essential. Even so, study results should be viewed as encouraging in that direction for improvements in model performance are being established.

CHAPTER 1

INTRODUCTION

1-1. BACKGROUND. The Tactical Effectiveness Testing of Antitank Missiles (TETAM) program was originated in December 1970 by Department of Defense Program Budget Decision 464. As originally defined, the program contained two major elements. Field Experiment 11.8 was conducted by the Combat Developments Experimentation Command (CDEC) in 1972-73 (reference 1). A detailed evaluation of the effectiveness of US antitank missile weapons based primarily upon data collected during Experiment 11.8 was conducted by the US Army Combined Arms Combat Developments Activity (CACDA) in 1973-74 (reference 2). In 1972, Department of the Army added a third major element to the TETAM program, that of evaluating the predictive ability of three of the Army's frequently used high resolution simulation models of tank-antitank warfare, using the results of Experiment 11.8 as a basis for evaluation. The resulting Model Verification Study was conducted by CACDA during the period October 1973 to October 1975.

1-2. OVERVIEW OF THE MODEL VERIFICATION STUDY.

a. Purpose and Objectives. The purpose of the Model Verification Study is to determine the ability of the DYNTACS, CARMONETTE, and Individual Unit Action (IUA) high resolution combat simulations to portray the outcomes of selected tank-antitank battles as carried out during CDEC Experiment 11.8 and to represent the major battlefield activities and processes leading to these outcomes. The specific objectives are:

(1) Determine the ability of each model to portray the outcome of Experiment 11.8 tank-antitank battles.

(2) Determine the degree of correlation between Experiment 11.8 and each model in portraying the following aspects of tank-antitank battles:

(a) Attacker-defender intervisibility.

(b) Movement of attacking forces.

(c) Target acquisition.

(d) Target handoff.

(e) Target assignment.

(f) Target engagement/kill.

(g) Combat intelligence.

(h) Communications.

(i) Supporting fires.

(The list of battle aspects to be considered varied during the course of the study. All items shown were identified as candidates for comparisons at one time or another during the study.)

(3) Identify the major underlying assumptions relevant to tank-antitank battles for each model.

(4) Identify and, where possible, prioritize needed modifications and/or improvements for each model.

b. Historical Narrative.

(1) Preliminary stages.

(a) Planning. Responsibility for accomplishing the Model Verification Study was initially assigned to the Systems Analysis Group (SAG) of the US Army Combat Developments Command. SAG had formulated a general approach to the model verification work by March 1973. At that time, as part of the 1973 reorganization of the US Army, responsibility for the study was transferred to CACDA. CACDA expanded this general approach into a specific concept for model verification, which was presented to the TETAM Senior Officer In-Process Review on 20 June 1973 (reference 3). This concept called for a sequential approach to model verification to begin with verification of each model's representation of intervisibility, followed by analysis of each model's play of detection and, finally, by an investigation of the weapon interactions in dynamic, force-on-force engagements. This approach followed the same general sequence established within the three major phases of CDEC Experiment 11.8. As illustrated in figure 1-1, each step was to involve a comparison of model and field results, determination of sources of observed differences, and corrective actions necessary to continue the process.

(b) Preparation. Of the three models to be evaluated, one (IUA) was the responsibility of CACDA from the outset of the study. Responsibility for a second model (DYNTACS) was transferred from SAG to CACDA in July 1973. This transfer did not include the transfer of personnel familiar with the model, and a program of formal training on the setup and operation of DYNTACS was conducted for CACDA programmers and analysts in November and December 1973 (reference 4). US Army Concepts Analysis Agency (CAA) agreed to operate the third model (CARMONETTE) in support of the model verification work. By mid-January 1974, all three models were being operated in support of the model verification objectives. Detailed intervisibility data collected in the execution of Experiment 11.8 were obtained from CDEC during the last quarter of 1973 and were in a form suitable for the comparisons in January 1974.

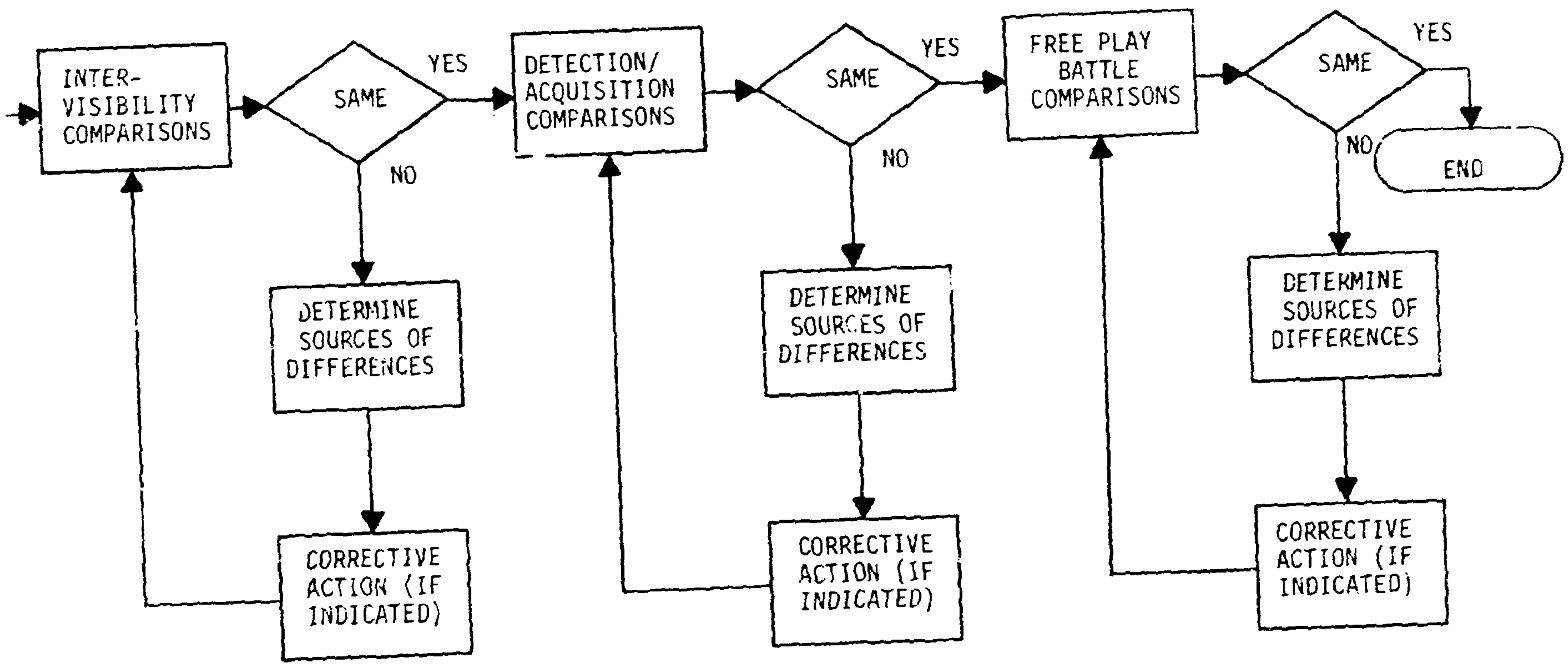

Figure 1-1. Sequential Nature of Model Verification

(2) Original intervisibility comparisons. The original comparisons of intervisibility data produced by the three models with the Experiment 11.8 intervisibility data were conducted during the period January through May 1974, and an interim report was published in June 1974. The original comparisons were conducted to determine whether the models portrayed intervisibility levels and patterns consistent with those observed in Experiment 11.8. It was anticipated that the level of disagreement between model and field results would be relatively minor and that work could progress into investigations of model representation of detection and battle free play with minimal model adjustments. Contrary to expectations, model results were found to be in serious disagreement with the intervisibility data collected during Experiment 11.8. The original comparisons are contained in this report.

(3) Approach to revision. The extreme disagreement between model and Experiment 11.8 realizations of intervisibility dictated that further project resources be expended to clarify the causes of this disagreement and to attempt to improve model representation of intervisibility. The study approach was revised to permit continued intervisibility work and, concurrently, to begin the necessary model preparation and field experiment review for the free play comparisons. The distinct study phase dealing with detection as an isolated process was estimated to require a resource increment approximately equal to that already expended on the intervisibility comparisons and was not amenable to initiation until the intervisibility situation had been resolved. Lacking such resources, the detection study phase was dropped from the approach. The revised approach was approved by the Model Verification Study Project Review Board on 15 October 1974. In the interim, the CAA commitment to operate CARMONETTE in support of the study had expired, and the follow-on work was limited to the DYNTACS and IUA models.

(4) Follow-on intervisibility comparisons. The second series of intervisibility comparisons was conducted during the period October 1974 to July 1975, with some preliminary excursions attempted in August and September 1974. This effort included a critical review of the field experiment as well as significant revisions to the DYNTACS and IUA representations of intervisibility. Additionally, a terrain representation model, which involved a significantly higher level of resolution than that found in the combat simulations, was investigated. This fourth model is a product of the Corps of Engineers Waterways Experiment Station (WES) and was operated by WES in support of the study. The follow-on intervisibility work resulted in representations of intervisibility within DYNTACS and IUA that were judged to be in sufficient agreement with the Experiment 11.8 data to allow the study to progress into the dynamic battle comparisons. This work is reported in Volume II (reference 5).

(5) Dynamic battle comparisons. The work leading to and actual comparisons of dynamic force-on-force battles as represented in IUA and

DYNTACS and as carried out in Experiment 11.8 was conducted during the period November 1974 to September 1975. A significant portion of this effort involved an extensive review of the experimental procedures and data. This review was required to develop a detailed appreciation of what actually took place in the free play trials of Experiment 11.8. This review and a comparison of model and field results for selected battles, as well as a critical review of model aspects for which no comparison data from Experiment 11.8 was available, are reported as the dynamic battle, or free play, portion of the Model Verification Study in Volume III (reference 6).

1-3. PURPOSE AND SCOPE OF REPORT. This report (Volume I) documents the work leading to and presents the results of the initial comparisons of intervisibility as represented by the CARMONETTE, DYNTACS, and IUA models with the intervisibility data collected during Phase I of Experiment 11.8. The findings and conclusions found in this report are based solely on these comparisons. Proper interpretation of these findings depends upon the results of both the follow-on intervisibility work initiated as a result of these findings (reference 5) and the dynamic battle comparisons (reference 6).

1-4. OVERVIEW AND REPORT ORGANIZATION.

a. Study Requirement. Each of the three models is designed to simulate the conduct of tank-antitank battles by playing in detail the fundamental battlefield activities of participating personnel and weapon systems and the environment within which these activities occur. A typical set of fundamental activities performed by an antitank weapon crew might occur in the following sequence: search for, detection, recognition, and identification of a target on the battlefield followed by loading, laying, and firing the weapon and guiding the antitank missile onto the target. In the models, as on the battlefield, the failure of a weapon crew to perform successfully any one activity in this sequence will normally prevent that crew from accomplishing the remaining activities in the sequence; that is, whether or not an ATM crew undertakes a particular activity is, in general, conditional upon success in the first activity, the search for and detection of a target. But detection is itself conditional upon the opportunity to detect. Within the context of the small unit tank-antitank battles of Experiment 11.8, opportunities for detection are those instances during which line of sight exists between attacking and defending elements. Thus, the occurrence of each of the fundamental activities previously discussed is either directly or indirectly conditional upon the existence of line of sight. For this reason, it was decided that a comprehensive evaluation of each model's ability to represent accurately the intervisibility conditions on the battlefield was a necessary first step in model verification.

b. Purpose. The purpose of the original intervisibility comparisons was to determine whether the three models predict levels and patterns of

intervisibility between attacking armored elements and defending antitank missile systems consistent with those observed during the TETAM intervisibility field experiments.

c. Approach. Intervisibility data collected at Hunter-Liggett Military Reservation during Phase IA of CDEC Experiment 11.8 were selected as the baseline against which model performance was to be evaluated. An examination of the design and conduct of the field experiment was conducted in order to determine the conditions under which the intervisibility field experimentation took place. The three models were then set up and run under conditions as close as possible to those of the field experiment, and the resulting model data were compared to those collected during the field experiment. These comparisons resulted in a number of findings regarding the degree of correlation between model and field results.

d. Study Methodology. Completion of the intervisibility study was contingent upon the accomplishment of the five major tasks shown in the schematic at figure 1-2. Each of these major tasks was in turn made up of several subtasks. These major tasks, their associated subtasks, and the sections of this report in which they are reported are outlined briefly below.

(1) Approach formulation. The development of a suitable approach to model verification was the initial problem to be solved. The results of this work are reported in the TETAM Model Verification Plan, USACACDA, 29 November 1973 (reference 3).

(2) Baseline definition. Considerable time and effort were expended in attempting to define precisely the Experiment 11.8 baseline against which the three models were to be evaluated. A review of experimental procedures is at chapter 2. Model comparison work centered on resolving three specific problems: the first was the problem of arriving at suitable corrections for the several different types of anomalies discovered in the intervisibility data provided by CDEC, the second was the problem of determining (primarily through an analysis of the design and conduct of the experiment) the quality of intervisibility data collected in the field, and the third was an attempt to determine through sensitivity analysis the extent to which errors in the field data might limit the usefulness of these data as a definitive comparison baseline. Work related to the first of these tasks is reported in appendix C and the sensitivity analysis at appendix B. As the remaining task is more closely associated with the interpretation of comparison results, discussions of this work are included in the report on the follow-on intervisibility work (reference 5).

(3) Model preparation and operation. Model preparation included the development of suitable inputs describing field experiment conditions for each of the three models and the design and implementation of model modifications so that appropriate model outputs could be extracted for the comparisons. In addition, a suitable plan for running the three models had to be devised and executed. Model preparation is discussed in chapter 3.

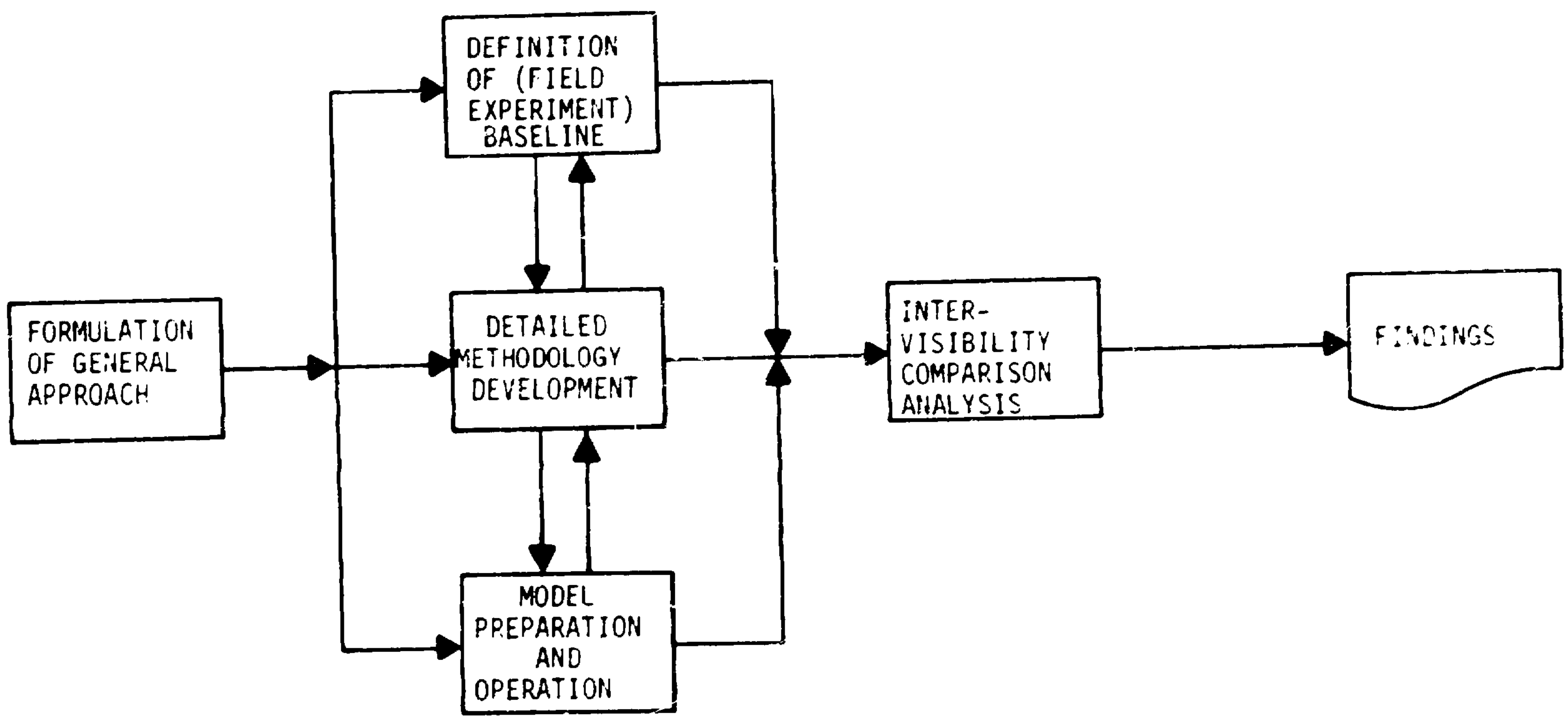

Figure 1-2. General Study Methodology

(4) Methodology development. Two separate types of methodology were under development during most of the study. The first of these is the overall study methodology outlined in this section. This task consisted of the identification of specific tasks to be performed during the study and the integration of these separate components into a coherent study effort. The second type of methodology developed during the study was the selection of a suitable set of procedures for performing the actual comparisons of model and field experiment data. These comparison methods are described in chapter 4.

(5) Comparison analysis. The final task consisted of actually comparing the model and field experiment data and identifying major differences between them. This work is described in chapter 5.

(6) Side analyses. Several side analyses conducted for two of the models are not explicitly identified in the study methodology described above. However, during the intervisibility study, certain aspects of the DYNTACS and IUA models were identified as requiring further investigation; and these investigations produced results with implications for model verification. The reasons for conducting these investigations, which generally involved limited sensitivity testing of the models, the results obtained, and their implications are reported in chapters 6 and 7.

(7) Study results. The principal findings of the initial intervisibility comparisons are presented in the final chapter of this report. In addition to these principal findings, a number of general insights related to the preparation, application, and verification of high-resolution combat simulations that resulted from this work are included at appendix E.

e. Applicability. Although the intervisibility study was restricted to examining explicitly the DYNTACS, CARMONETTE, and IUA models, it should be noted that the Bonder analytical models (Bonder IUA and Air Cavalry 5) share the IUA preprocessor programs that determine intervisibility and movement. Thus, the results of intervisibility comparisons reported here for IUA are also applicable to the Bonder IUA and Air Cavalry 5 models.

CHAPTER 2

THE INTERVISIBILITY FIELD EXPERIMENT

2-1. GENERAL. One of the objectives of CDEC Experiment 11.8 was to collect data suitable for use in model verification. Thus, detailed intervisibility data were available from the field experiment for use as a standard against which to evaluate model performance.

a. Phase I, CDEC Experiment 11.8 was conducted during March through December 1972 to collect data on the frequency and duration of intervisibility between defensively emplaced antitank missile weapons and advancing enemy armored vehicles. These data were collected on 12 sites in West Germany, 2 sites at Fort Lewis, Washington, and 2 sites at Hunter-Liggett Military Reservation (HLMR), California.

b. The intervisibility data collected at Hunter-Liggett were selected for use in evaluating model performance because all data other than the intervisibility data produced by Experiment 11.8 were collected only on the Hunter-Liggett experimentation sites. Selection of the Hunter-Liggett sites also provided an additional benefit. Because the two experimentation sites at HLMR overlapped, and because intervisibility data were collected for two separate sets of attacker approach policies on one of these sites, three complete sets of field experiment data were available for use in the comparisons at a cost of preparing only one set of terrain data for each model.

c. A complete description of the collection of intervisibility data at HLMR is contained in Volume IV, Final Report, CDEC Experiment 11.8 (reference 1d) and is not repeated here. However, a working knowledge of certain aspects of that experiment is necessary for full understanding of the conduct of and results provided by this study. Therefore, a summary of those aspects relevant to the model verification work is provided here for convenience.

2-2. CONDUCT OF THE FIELD EXPERIMENT. Phase IA (Intervisibility) of Experiment 11.8 was conducted at Hunter-Liggett Military Reservation, California in September and October of 1972. Intervisibility data were collected on two partially overlapping 2x5 kilometer terrain sites, the characteristics of which were distinctly different. Thus, field data were produced that made possible an evaluation of model performance in two diverse terrain environments.

a. Experimentation Sites. On Site A, a defensive position was selected on a dominant hill mass overlooking relatively flat, open enemy avenues of approach. Site A afforded the defenders nearly ideal conditions for long range observation and fires out to 2,500 meters with many opportunities at ranges well beyond. The defensive position on Site B was located on the floor of a gently rolling valley. This position was only slightly higher than the enemy avenues of approach into the defensive

position and, for that reason, the trees scattered throughout the site significantly reduced observation and fields of fire. Even so, many opportunities for observation and antitank missile (ATM) fires existed out to 1,500 meters though opportunities beyond that range were few.

b. Defender (ATM) Positions. Thirty-six positions suitable for use as antitank missile systems emplacements were selected on each site. A tricolored panel was placed on each position with three horizontal color bands representing the heights of the M551, M113-mounted TOW, and ground-mounted TOW (and DRAGON).

c. Attacker Routes. On each site, 10 attacker approach routes were established such that each route represented a tactically realistic approach for armored vehicles assigned the mission of closing with the defensive position as rapidly as possible. An additional set of 10 routes was established on Site A in order to collect intervisibility data for a situation in which the attacking force would attempt to take maximum advantage of available cover and concealment en route to the objective. Thus, three separate sets of intervisibility data were collected at Hunter-Liggett.

d. Measurement Interval. Specific points from which intervisibility data were to be collected were established at intervals of approximately 25 meters along each of the 30 routes. These viewing points were marked with stakes driven into the ground and, for convenience, are referred to as "stakes" throughout this report. The location of the defender weapon positions and of selected stakes on each route were determined by the CDEC Range Measuring System to a stated accuracy of ±5 meters in each coordinate.

e. Attacker Heights. At each stake, data collection teams determined whether or not line of sight existed to each of the 36 defender weapon positions from two different heights, which represented the heights of the driver of the threat tank and the highest point on the threat ATM vehicle, respectively.

f. Height Combinations. By recording the lowest color band visible at each of the tricolored panels from the two heights at each stake, data teams were able to collect intervisibility data for six combinations of attacker and defender weapon height. In addition, each team recorded its judgment as to the reason for nonexistence of line of sight whenever one or more color bands could not be seen.

g. Data Collection Procedures. Data were collected by two-man teams. At each stake, one team member determined whether line of sight existed to each of the defender panels through the use of a telescope (or binoculars), a step ladder, and a photograph of the defensive position showing the location of each panel; the other team member recorded this information on specially labeled and perforated "port-a-punch" cards. Each team

began collecting data on those of its assigned stakes nearest the defensive position and then proceeded sequentially along its assigned path to those at greater ranges.

2-3. SUMMARY OF DATA COLLECTED. The field experiment produced three separate sets of intervisibility data at Hunter-Liggett, one for each terrain site-approach tactic combination. Each set of intervisibility data contained the following basic information.

a. The UTM coordinates of each defender (ATM) position with a reported accuracy of ±5 meters in the X and Y coordinates.

b. The UTM coordinates of selected stakes on each attacker route (to the same accuracy).

c. The existence or nonexistence of line of sight between the 36 defender positions and each of the 1,500-2,000 stakes for each of the six attacker-defender height combinations.

d. The data collector's recorded judgment as to the reason for nonexistence of line of sight whenever it did not exist.

2-4. REPORTED QUALITY OF DATA COLLECTED. The final report on CDEC Experiment 11.8 (reference 1d, appendix A) contains a detailed report on the quality assurance procedures of the intervisibility field experiment. The salient aspects of this quality assurance program are summarized below.

a. Procedures. Quality control procedures aimed at insuring that no more than 5 percent of the field experiment data would be in error were an integral part of the design and conduct of the experiment. Several specific facets of quality control are of particular interest.

(1) Overlap. Three teams were assigned to collect data on each of the 10 paths, with each team responsible for slightly more than one-third of its assigned path. This assignment provided for an overlap of 21 stakes between each pair of adjacent data collection teams, thus providing two full sets of intervisibility data for 42 of the stakes on each path.

(2) Spot check. An additional check on the quality of the data was provided by a number of spot checks. Each of five spot check teams collected LOS data at eight consecutive stakes on each of the 10 paths. These teams were instructed to concentrate their efforts on portions of the paths where intervisibility existed. Spot check teams collected data only as to the existence or nonexistence of line of sight and only from the high attacker height.

(3) Remeasurement. Before data were accepted from any data collection team, these data were compared against those of the adjacent

data collection team(s) to determine whether the team's data were of acceptable quality. The criterion for data acceptability was that no more than 5 percent of the data could be in error. Whenever data from a team were determined to be of less than acceptable quality, data for the portion of the path to which that team had been assigned were retaken.

b. Error Estimate. The CDEC final report indicates that these procedures were effective in limiting errors to no more than 5 percent of the data collected. It further indicates that the analysts responsible for implementing and monitoring these procedures in the field felt that about 2 percent would be a better estimate of the amount of line-of-sight data in error. However, no formal analysis of the various types of errors and the frequency with which they occur in the intervisibility data is available.

2-5. DATA PROCUREMENT. These field experiment data were originally recorded on specially labeled, preperforated "port-a-punch" cards issued to the data collection teams in the field. They were subsequently edited, reformatted, and merged into a single automated data base at CDEC. In the process, all but one set of observations for each stake were purged from the data base. These edited data were provided to the study team on punched cards.

2-6. DATA EDITING. The study team found it desirable to reformat the data provided by CDEC, and, in the process of accomplishing this revision, identified several types of anomalies in the field data. As others may find applications for this CDEC data base in the future, a discussion of the work performed in cleaning up these data problems is presented in appendix C. Essentially, the study team, with assistance of analysts from Braddock, Dunn and McDonald's Scientific Support Laboratory (BDM/SSL) at Hunter-Liggett, identified and implemented corrections to these data anomalies which were, in many cases, based upon study team and/or BDM/SSL judgments as to most reasonable treatment. Although the extent to which these corrections reflect field experiment reality is unknown, these data problems were confined to 0.5 percent of the data collected on Site A and to about 4 percent of the data from Site B.

CHAPTER 3

MODEL PREPARATION

3-1. GENERAL. The preparation of each of the three models proceeded concurrent with the preparation of field experiment data described previously. The DYNTACS(X) and IUA models were prepared and operated by members of the study team at CACDA. Preparation and operation of the CARMONETTE VI model was accomplished at Concepts Analysis Agency based upon guidance and direction provided by the CACDA study team. The design and conduct of the intervisibility field experiment provided the foundation upon which all the model preparation work was based. This approach was necessary to insure that line-of-sight (LOS) data produced by the three models would be suitable for comparison with corresponding data from the field experiment. The various activities composing the model preparation work generally contributed to the accomplishment of one of three major tasks: (1) the development and preparation of model inputs, (2) the extraction of the appropriate line-of-sight outputs, and (3) the integration of model modifications designed to make the procedures for collecting LOS data from the models similar to those used in the field. The purpose of this chapter is to outline in general terms how these tasks were accomplished.

3-2. DATA DEVELOPMENT POLICIES. As the data collected during the intervisibility field experiment provided the baseline against which model performance was to be evaluated, it was necessary to reproduce in the models conditions as close as possible to those of the field experiment. This approach was necessary in order to insure that deviations from the actual field experiment conditions would not contribute appreciably to differences observed between model and field experiment results. Thus, two basic policies governing the development of model inputs were adhered to throughout the model preparation work. First, input data for the three models had to conform to and be developed from those of the field experiment to the extent possible consistent with model design. As stated previously, comparability of inputs was necessary in order to eliminate inputs as a source of any differences between model and field experiment results. However, it was also necessary to insure that model inputs were developed in a manner consistent with each model's design philosophy so that model results could be considered representative of model capabilities. The second policy governing data development dictated that whenever development of model inputs required the estimation or assignment of a parameter to which more than one value reasonably might be assigned, a single best estimate of the required parameter would be assigned a priori for the base case evaluations of model performance. This approach precluded the use of iterative revision of input parameters and was appropriate in that no basis for revising these estimates is normally available to the model user. The basic purpose of these two policies was to guide the development of model inputs so as to produce, under controlled conditions, results representative of model performance in typical applications.

3-3. INPUT DATA DEVELOPMENT. The importance of insuring comparability of model and field experiment inputs was recognized early enough to permit the orderly development of model inputs in accordance with the two policies outlined above. Table 3-1 summarizes the principal model inputs affecting line of sight and provides some indication of the extent to which the study team was successful in achieving comparability of inputs. The development of each of these principal inputs for the three models is discussed in general terms below.

a. Terrain Data. Each of the models requires that a detailed terrain data base be developed as input for the model. Two specific criteria were established for the preparation of terrain data for the models. First, terrain data were to be developed to describe as closely as possible the two terrain sites on which the field experiment was conducted. Second, where similar terrain inputs were required for two or more models, a common procedure for developing those inputs was to be used whenever possible. Terrain data were derived from several different sources. Elevation data for DYNTACS and CARMONETTE were developed at Defense Mapping Agency from 1:25,000 scale military mapsheets using automated procedures. Elevation data for IUA were extracted by hand from mapsheets of the same scale and quality. Elevation inputs for the models were developed at the following resolutions: the interval between uniformly spaced elevation points for DYNTACS was established at 95.25 meters; the CARMONETTE grid size was set at 100x100 meters; the mean area covered by an IUA triangle was 36,800 square meters. Waterways Experiment Station (WES) provided data describing the vegetation, soil types, and surface roughness of the Hunter-Liggett terrain sites. This information was transformed at CACDA onto separate acetate overlays describing (cover and) concealment, soil type, and roughness from which certain types of terrain data for the models were then developed. The vegetation data provided by WES did not provide sufficient information from which to develop values for all model parameters (particularly for DYNTACS) so this information was supplemented by additional data collected during on-site inspection of the HLMR sites by members of the study team.

b. Attacker Weapon Heights. The two at[illegible] heights from which data teams collected line-of-sight data during the field experiment represented the heights of the driver of the threat tank and the highest point on the threat ATM vehicle, respectively. These two heights were input to all three models.

c. Defender Weapon Heights. The three horizontal color bands on the panels placed at each defender (ATM) position represented the heights of the M551 Sheridan, the TOW mounted on the M113 personnel carrier, and the ground mounted TOW (or DRAGON) weapon systems. The actual heights of these color bands were used as inputs to all three models. It should be noted that IUA does not normally provide for an input of this type. In IUA, line of sight from points along the attacker routes is computed to only a limited number of points (objective points) within the defensive position. These objective points are placed in the center of groups of

Table 3-1. Comparability of Principal Inputs

Principal Inputs	Field Experiment	DYNTACS(X)	CARMONETTE*	IUA
Terrain Site	Hunter-Liggett	Same	Same	Same
Elevations	Actual	Def Map Agency	Def Map Agency	Map Sheet
Vegetation	Actual	Waterways	Waterways	Waterways
Defender Locations	Actual	$\pm$20 m (approx)	Nearest Grid	$\pm$10 m
Defender Wpn Heights	44-72-116"	Same	Same	Same
Attacker Routes	Actual	$\pm$10 m	Nearest Grid	$\pm$10 m
Attacker Wpn Heights	48-84"	Same	Same	Same
Sighting Interval	25 m	Same	100+ m	30 m

*Indicated sources are for inputs used for Site B comparisons. In general, inputs for Site A CARMONETTE runs were those prepared for earlier (1972) TETAM work.

defender weapons and if line of sight exists from a point on an attacker route to an objective point, LOS is assumed to exist to all defender weapons in the vicinity of the objective point regardless of their height. Thus, the concept of specific defender weapon heights, which is not normally provided for in the IUA model, was introduced artificially for the model verification work.

d. Defender Weapon Locations. Even a hasty review of the field experiment data indicates that panel location is a critical factor affecting line of sight. The field experiment data contain a number of cases in which intervisibility data recorded for two panels in close proximity are completely different. For this reason the accuracy with which defender weapon locations in the models reflected field experiment reality was important in obtaining valid comparison data. The actual locations of defender weapons (panels) in the field were determined through the use of the CDEC Range Measuring System at Hunter-Liggett, and these locations were provided to the study team as 10-digit UTM coordinates. These UTM coordinates were then converted to model coordinates using the standard analytic geometry formulas for translating and rotating axes. Difficulties were encountered in transforming UTM coordinates to the DYNTACS coordinate system primarily because some ambiguity surrounded the procedure for identifying the exact locations of the digitized elevation points provided by Defense Mapping Agency for use in DYNTACS. This problem was never completely resolved, but it is estimated that defender (panel) locations in DYNTACS were typically within 20 meters of the field experiment locations reported by CDEC. CARMONETTE requires only that defender weapons be located in the correct 100-meter grid square and this was accomplished without difficulty. While precise defender locations can be provided to IUA, the model actually determines intervisibility to attacker route objective points and ascribes this result to associated defender weapons. The points used in model runs and associated weapons are presented in appendix D.

e. Attacker Routes. It was also important to insure that the actual attacker routes established for the field experiment would be followed as closely as possible in the model runs. This was necessary so that intervisibility data produced by the models would not be collected for vehicles traversing essentially different paths from those used in the field experiment. The UTM coordinates of selected stakes along each route (typically, every other stake) were determined by the CDEC Range Measuring System (RMS). These coordinates were provided to the study team in automated form as part of the field experiment punch card set. The coordinates of those stakes for which locations had not been determined by the RMS were established by the study team by linear interpolation from the position data available. Thus, approximate UTM coordinates were available for all stakes on all paths, with the number of stakes on a path ranging between 130 and 230, depending on path length.

(1) DYNTACS. Because attacker routes are selected dynamically in DYNTACS based upon terrain difficulty and the enemy situation on each route, there are a number of difficulties associated with restricting attacker movement to specified routes in the DYNTACS model. For this reason, the DYNTACS line-of-sight routines were extracted from the model and operated by a specially written driver routine so that the exact coordinates of each stake could be used in the DYNTACS runs. The preparation of inputs specifying attacker routes for IUA and CARMONETTE, however, presented a different problem.

(2) IUA. IUA allows a maximum of 30 coordinates to be input specifying each attacker route. Because of the importance of adhering to the field experiment routes as closely as possible, it was decided that these points describing each model route should be selected through optimization procedures. The problem was to select a subset of 30 or fewer stakes from the set of all stakes on each route such that the total deviation of the model route from the field experiment route was minimized. The problem was formulated as a problem in dynamic programing and was solved on the computer, thus providing sets of optimal route descriptor points for IUA for all 30 routes used in the field experiment. This procedure is documented in appendix D.

(3) CARMONETTE. Attacker routes for CARMONETTE are specified in terms of the attacker's progression through a series of adjacent terrain grids. Because the size of the grid was established at 100 meters on each side during the coding of terrain data, the specification of about 30 grids was required to describe fully each attacker route. The sets of optimum stake locations previously selected for IUA were also found to be suitable for use as the CARMONETTE grid sequences for each attacker route.

f. Measurement Intervals. The capability for controlling through explicit model inputs the frequency with which line of sight is computed is provided for only in the DYNTACS model. This problem was handled in a different manner for each of the three models.

(1) DYNTACS. In normal applications, users of DYNTACS are required to specify by input the duration of a movement event (in seconds), and line of sight is normally computed from the "current" element to every enemy element at the end of the current element's movement event. However, the operation of the DYNTACS line-of-sight routines independent of other submodels precluded control of the frequency of computation through the use of this feature, and an alternate procedure had to be developed. An appropriate solution to this problem was to compute line of sight from the locations of every stake in the field experiment. This approach, of course, would produce model results that are not necessarily representative of model performance in a typical model application because line of sight is normally computed less frequently. Under this approach,

if model and field experiment intervisibility results proved to be similar, further analysis would be necessary to evaluate the effects of using a more representative computational frequency. However, if these results were appreciably different, it could be concluded that a different computational frequency was not likely to improve these results.

(2) IUA. No provision for changing the frequency with which LOS is computed exists in IUA. Line of sight is computed at every route descriptor point and at 30-meter intervals (approximately) between route descriptor points. For this reason, the IUA runs produced about 10 percent fewer data points than were collected during the field experiment; and these data, though computed from along the same attacker routes, were seldom computed from the exact field experiment stake locations. However, these LOS data should be considered representative of those produced during a typical IUA run.

(3) CARMONETTE. The frequency with which LOS is computed in CARMONETTE is specified implicitly when the grid size is established during the preparation of terrain data. The 100-meter grid size used for the model runs is typical of the terrain resolution used historically in CARMONETTE study applications. Because of this relatively large grid size, CARMONETTE produced only about one-fourth as many data points as the field experiment. However, these data should also be considered representative of those produced by and used during typical CARMONETTE runs

3-4. EXTRACTION OF MODEL OUTPUTS. During normal model runs, each of the three models performs a considerable number of logical checks and mathematical computations to determine whether line of sight exists between the pairs of points on the battlefield that are of immediate interest at a particular time during the simulated battle. However, the models do not maintain records of these data other than to store them temporarily to satisfy the immediate needs for information of this type. It was therefore necessary to modify the three models to provide for extraction of these intervisibility data. To insure that valid comparisons between model and field data could be made, it was determined that intervisibility data extracted from the models should be comparable to the field data in three respects. First, model outputs had to be of the same fundamental nature as those collected during the field experiment. Primarily, model data had to describe whether or not line of sight existed between various points on the battlefield. Second, the intervals along the attacker routes at which these data were to be taken in the models had to be comparable to those used in the field to the extent possible consistent with model design. (The extent to which comparability in this respect was attainable was described in paragraph 3f of this chapter and is not repeated here.) Finally, it was necessary to insure that each model would play all factors affecting line of sight in the field experiment within the constraints of model design. The extent to which comparability of model outputs was achieved is outlined below.

a. Nature of Model Outputs. The series of logical checks and mathematical computations used by each of the three models are designed to produce the same basic information as that collected during the field experiment; that is, they determine whether line of sight exists between two specific points on the battlefield. Therefore, the fundamental data needed for an evaluation of each model's ability to play line of sight were readily available within the models, and the only difficulty presented was the technical problem associated with extracting and recording these data. In addition, each of the three models in normal operation determines, in some fashion, the degree to which the target vehicle is concealed from observation and direct fires from the observer position. Thus, some data available within the models were roughly comparable to the field experiment data describing reasons for the nonexistence of line of sight. These model data were extracted and transformed into data roughly comparable to the field data, but they were not used in the model comparisons because it was recognized that the models would always know why LOS did not exist but participants in the field experiment sometimes could only guess. Further, it appeared likely that LOS could be interrupted at more than one point between the observer and target for more than one reason. It was not clear what decision logic was used in the field when this condition was perceived. However, the fundamental data essential for model verification were available within each model, and the model modifications necessary for extracting them were accomplished without major difficulty.

b. Factors Affecting Intervisibility. As the study proceeded, it became increasingly apparent that a number of factors affecting intervisibility might receive different treatment in the field experiment and in one or more of the models. These differing treatments, which stemmed from both model and field experiment design, were examined on a case by case basis as they were identified. The principal consideration in determining whether action was necessary in each case was the need for maintaining an acceptable balance between attaining model results representative of model capabilities in normal application and controlling extraneous sources of variation between the models and the field experiment. Each of the factors identified as receiving different treatments and the extent to which these problems could be resolved are outlined below.

(1) Direction of observation. All intervisibility data collected during the field experiment were produced by data teams observing from points along the attacker routes to the panels on the defensive position. While this procedure is always used in IUA for computing line of sight, during normal operation of DYNTACS and CARMONETTE, LOS is computed from the "observer's" position regardless of whether that element is an attacker or defender. This potential problem was eliminated by making the LOS computations in all three models from points along the attacker routes.

(2) Definition of intervisibility. For purposes of collecting field data on Site A, intervisibility was said to exist between two points whenever either could be seen from the other. This working definition of intervisibility made no provision for those cases in which line of sight existed but the terrain was not sufficiently open to permit the employment of antitank missiles (e.g., data collectors had to look through nearby tree branches to see a defender panel). This working definition is also used by all three models so no real problem existed with respect to comparability of data collected for Site A. However, this definition was modified somewhat during the collection of field data on Site B. On Site B, data collectors were required to identify those cases in which LOS existed but missiles could not be used. Fortunately, the procedure used in the field for recording this additional information merely called for the addition of a flag to the basic data in order to indicate the existence of this special condition. Thus, intervisibility data as defined by the original definition was recovered from the field data by simply ignoring these flags, thereby avoiding the possibility of different definitions of intervisibility in producing the model and field data. It should be noted that the study team's decision to follow this approach in no way indicated that either of these definitions is preferable to the other. In fact, the latter definition appears to be appropriate for simulating actual engagements involving antitank missiles, while the former is preferred for examining the detection cycle.

(3) Vegetation play. The various ways in which the models handle vegetation was another area of concern. While unsuitable representation of vegetation in a model was generally to be treated as a model deficiency rather than as a source of extraneous variation between model and field experiment, some modification to the original terrain data prepared for the models was necessary to insure that model and field experiment results would be comparable. Model inputs describing vegetation on the experimentation sites were developed using procedures prescribed by the model documentation. The approach normally followed in using all three models is to develop terrain inputs independent of the tactical plan, then to overlay the tactical situation on the terrain and play the battle. This approach is somewhat fallacious because it underemphasizes the extreme importance of vegetation in the immediate vicinity of the defensive (target) positions. For example, because a considerable portion of the defensive position on Site A was covered by dense forests, the terrain data originally prepared for the models depicted forests on the defensive position. In the model test runs, this vegetation often produced complete blockage of line of sight to defender weapons located within the forested areas. Yet, defender weapon positions in the field experiment had been selected primarily for their long range observation and fires. Because conscientious model users probably would have identified and corrected this discrepancy in normal model applications, it was decided to strip

the forest data from the areas in which defenders were positioned, thereby enabling these weapons to enjoy in the models the long range observation and fires to which they were obviously entitled.

3-5. SUMMARY OF MODEL PREPARATION. Preparation of the models consisted of accomplishing three specific tasks: sets of inputs for the models comparable to those of the field experiment had to be identified and prepared, the model modifications necessary to extract comparable output data from the models had to be designed and implemented, and several possible sources of extraneous variation between model and field experiment results had to be investigated and dealt with. Completion of these preparations provided three models set up to produce (1) intervisibility data for conditions similar to those of the field experiment, and (2) model results that could be considered generally representative of model capabilities in typical applications.

CHAPTER 4

COMPARISON METHODOLOGY

4-1. GENERAL. Earlier in this report, the distinction was made between the development of study methodology and comparison methodology, with the latter being defined as the selection of a suitable set of procedures for comparing model and field experiment data. From the early stages of the study it was obvious that quantitative comparisons between the results of the models and the field experiment were highly desirable; however, the identification and final selection of suitable comparison variables and comparison procedures constituted a sizeable research and analysis task. The purpose of this chapter is to describe those variables and procedures selected and to outline, where appropriate, the rationale underlying their selection.

4-2. STANDARDS. Because the ability of tank and antitank weapon crews to acquire, engage, and neutralize hostile elements is dependent on the existence of line of sight, it appeared that a model would have to represent intervisibility with considerable accuracy in order to produce a reasonably accurate simulation of tank-antitank battles. Ideally, the models would produce correct LOS determinations between every stake and every panel for each of the six combinations of the attacker and defender height. While such total representation of the real world may not be attainable, it is clear that the models' representation of LOS must be accurate in several respects considering the uses the models will make of the representation. First, the total amounts of LOS have to be accurate to keep weapons possessing specific capabilities (e.g., high rate of fire, high probability of kill) from being placed at an unfair advantage (or disadvantage) in the models. Second, because the target acquisition, engagement, and neutralization processes are range related, these areas of line of sight must occur at the right general battlefield locations in the models. Third, the models have to describe accurately the LOS conditions between the specific areas to be occupied by defender weapons and each of the various areas to be traversed or occupied by attacker elements. Fourth, the LOS data from the models have to differentiate accurately among different attacker and defender weapon heights so that LOS between specific types of attacker and defender weapons is portrayed correctly. Finally, the tendency of LOS "YES" determinations to occur consecutively (in strings) must be represented accurately by the models in view of their use in the logical structure of the models.

4-3. DIVERSE APPROACH. As the study team became more deeply involved in the intervisibility study, it became increasingly apparent that more than one approach had to be taken in comparing the model results to those of the field experiment for several reasons. First, the study team was unable to identify any single comparison procedure that would be fully sufficient for determining whether acceptable accuracy of LOS representation was achieved by a model with respect to all these different accuracy

requirements. Second, the use of several different procedures in performing these comparisons provided for lower risk in the sense that a mistake made in applying an appropriate technique or the application of an inappropriate technique would not necessarily invalidate study findings. Finally, examination of the data through the use of several different procedures provided an increased understanding of model results and assisted in isolating particular trends. Thus, it was decided that the use of several different procedures for comparing model and field experiment results was indicated.

4-4. COMPARISON VARIABLES. The desirability of using several different procedures for comparing the model and field data and the requirement for examining the accuracy of LOS data from the models with respect to several different criteria necessitated the use of several comparison variables. All of these variables were derived from the fundamental line-of-sight determination (YES or NO) data, and each is discussed briefly below.

a. Fundamental LOS Data. The fundamental data collected from the field experiment and the models were the basic LOS "YES or NO" determinations between each stake and each panel for each height combination. Of the models, only DYNTACS collected these LOS data from the exact stake locations used in the field experiment; therefore, only the DYNTACS results could have been compared to these data on a one-for-one basis. Because of the desirability of evaluating the performance of all three models using the same comparison variables and methods, it was decided that this comparison variable would not be used directly in the comparisons.

b. Number of LOS Segments. Initially, the "line of sight segment" characterization of intervisibility appeared to be attractive for comparing model and field experiment intervisibility for several reasons. However, the study team developed a number of reservations concerning the suitability of the LOS segment as a comparison variable; and, in the final analysis of model performance, the use of the LOS segment was deemphasized.

(1) Relevance. Insight into the relevance of the LOS segment characterization of intervisibility is provided by the following discussion. Line-of-sight determinations in the models play an important role in establishing the logical progression of simulated battlefield activities. On any number of occasions during a simulated battle, the selection of an appropriate succeeding activity for an element hinges on the outcome of an LOS determination. Thus, a representative logical progression within the simulated battle is established only when these line-of-sight determinations accurately reflect the actual LOS conditions of the battlefield. This problem is complicated by the introduction of a sampling problem since the models do not check LOS continuously. Thus, a comparison variable that requires the models to assemble these fundamental LOS "YES" determinations into correct patterns was needed. The

bivariate distribution of line-of-sight segments (categorized by length of segment and range at segment initiation) appeared to do precisely that.

(2) Limitations. A major limitation of the LOS segment as a comparison variable was identified during the sensitivity analysis performed on the field experiment data (see appendix B). One of the findings of that analysis was that the LOS segment characterization of intervisibility exhibits sensitivity to relatively small changes in the fundamental LOS data from which the segments are derived. Because the study team was unable to rule out the possibility that a moderate error rate exists in the fundamental data collected in the field, it was decided that the use of LOS segment distributions involved a moderately risky approach to making direct comparisons between model and field results. Thus, these derivative data were used only to gain insights into the extent to which the models tended to produce unbroken strings of LOS "YES" determinations.

(3) Observation. One observation should be made concerning the sensitivity of the LOS segment distributions. It appears that the procedure used for classifying the segments according to the ranges at which they occur is a major contributor to the sensitivity of these distributions. For example, changing the LOS determinations at, say, three stakes along a continuous segment of 3,000 meters length not only produces a total of four segments in place of the previous one, but three of the four segments may then be reclassified into completely different range bands than the one used previously. Thus, not many changes in the underlying data need to be made before the (bivariate) distribution of LOS segments bears little resemblance to its original form. It seems likely, however, that a suitable classification procedure can eventually be devised that would permit reliance on the LOS segment as a principal comparison variable. If so, the benefits to be realized are considerable because the LOS segment provides a direct measure of most of the relevant aspects of intervisibility.

c. Number of Stakes with LOS. Each LOS "YES" determination between one stake and one panel was termed a "stake with LOS" for purposes of discussion. Thus, the number of stakes with LOS is merely a cumulation of all the individual "YES" determinations. Stakes with LOS were classified by path, range band, and defender weapon; and these data formed the basis for most of the conclusions that resulted from the intervisibility study. Two points should be made concerning this comparison variable. First, this variable differs from the fundamental LOS data only in that an aggregation of stakes is made within each 500-meter range band on a path. Thus, this variable is only as sensitive to error in the underlying data as are the underlying data themselves. Second, because LOS data for fewer stakes were produced by both IUA and CARMONETTE than were collected in the field, an adjustment to the number of stakes with LOS produced by these models was necessary to make the data comparable to those of the field experiment. The actual adjustments made are described in chapter 5.

d. Amount of Battlefield Visible. One additional comparison variable was used that requires some explanation. The total length of all LOS segments was computed for each site (and height combination) and is referred to as the "amount of battlefield visible." This statistic is an aggregation over all defender weapons (panels) and all stakes (thus, all paths and all range bands), and it provides an indication of the overall openness or closeness of the battlefield. Major differences in this statistic between model and field data indicate that major differences between the two necessarily exist, though close comparability would not necessarily mean that model and field results agree with respect to the important criteria discussed in paragraph 2 of this chapter. It should also be noted that this statistic is also only as sensitive to error as the fundamental field data themselves.

4-5. COMPARISON METHODS. Comparisons between the model and field data were made by applying simple mathematical techniques, standard statistical tests, and subjective judgment to the comparison variables described above. The simple mathematical methods and the uses of subjective judgment require little explanation and are therefore described within the analysis in chapter 5. However, the statistical procedures are more involved and are described below.

a. Application. Three types of statistical tests were used in comparing the model and the field experiment data: the three-way χ^2 contingency table, the T-test for paired observations, and the nonparametric sign test. These three tests were applied as a set and were used to compare model and field experiment data for both LOS segments and for the numbers of stakes with LOS.

(1) LOS segments. Line-of-sight segments were categorized with respect to their length and the range at which they were initiated, thus creating a bivariate distribution of LOS segments. Since these distributions existed for both model and field experiment data for each site and all attacker-defender height combinations, these bivariate model and field experiment distributions could be compared for any height combination on any site.

(2) Stakes with LOS. A similar procedure was applied to the stakes with LOS from the model and field data. Bivariate distributions were formed by classifying each stake with LOS with respect to path and range band (aggregating over all defender weapons). Again, separate distributions were created for each height combination on each site.

b. Procedure. Because the procedure applied was the same regardless of which of the two comparison variables was used, the procedure is described below only as it was applied to the bivariate distributions of LOS segments, with the understanding that the same description applies to the testing of stakes with LOS.

(1) Description. In applying this procedure, a three-dimensional matrix was formed by using the appropriate bivariate distribution from the model as level (page) one and that from the field experiment as level (page) two. This matrix was used to test the null hypothesis that the source of the data (model or field experiment) is independent of the other two classification criteria; that is, this test for independence determines whether the bivariate distributions of these occurrence data are the same. The statistical representation of this null hypothesis is:

$$p_{ijk} = p_{ij}p_k$$

The probability of being in cell i,j,k is the product of the maximum likelihood estimate of the probability of having a particular i,j pair of values and the maximum likelihood estimate of the probability of having a particular k value. The probability of having an LOS segment in a given cell is used to calculate the expected number. The expected number is used to calculate the test statistic:

$$\sum_{i,j,k} (\text{observed number-expected number})^2 / \text{ expected number}$$

The test statistic has a limiting distribution of χ^2 and has (I*J-1)(K-1) degrees of freedom.

(2) Limitations. Two problems exist with the χ^2 test. First, the expected frequency of observation should be at least five for each cell. Since there were large areas of sparse data in the typical LOS matrix (and some in the stakes with LOS data), the matrix had to be contracted by combining rows or columns until the minimum expected numbers of observations were attained. The general rule in grouping these data was to preserve as many degrees of freedom as possible. The χ^2 test was then applied to the contracted matrix. The second limitation of the χ^2 test is that it only determines whether the model and field experiment distributions are the same. Thus, the model could theoretically produce 10 times as many LOS observations as the field experiment and still pass the χ^2 test provided that line of sight was similarly distributed. Therefore, it was also necessary to test whether the total number of occurrences was the same. For this reason, two additional tests were added to form a three-test statistical package. For the first additional test, the page one entries (model data) and page two entries (normally CDEC data) with the same I and J values in the contracted matrix were considered to be a pair of observations. The page one entry was subtracted from the page two entry to form an I by J difference matrix. The mean and variance were computed for the entries in this difference matrix using maximum likelihood estimates. The T-test was then used to test the hypothesis that the mean of the values in the difference matrix was zero. The second test added was also performed on the values in the difference matrix. The nonparametric sign test was used to test

the null hypothesis that the probability of a minus sign was 0.5. If it was not possible to reject the null hypothesis for either of these additional statistical tests, then the two data sets were said to have the same number of elements.

4-6. SUMMARY. A suitable methodology had to be developed for determining whether differences existed between intervisibility results of the models and the field experiment. Methodology development consisted of (1) identifying those criteria with respect to which model and field results had to agree closely, and (2) selecting suitable comparison variables and procedures. The successful completion of this work enabled the study team to perform the model-field experiment comparisons described in the next chapter.

CHAPTER 5

COMPARISON ANALYSIS

5-1. GENERAL. As the preliminary work described in the preceding sections neared completion, a suitable plan for running the three models was finalized and the model runs were begun. This plan called for three basic runs of each model, one for each of the three field trials that produced the CDEC intervisibility data; and each run was designed to produce data that could be considered representative of the model's capabilities. Analysis of the preliminary model runs revealed a number of errors made by the study team in setting up and operating the three models. Several runs of each model were actually required before the study team was satisfied that problems of this nature had been eliminated. Once these problems were overcome, a series of comparisons between data produced by each model and by the field experiment was performed. These comparisons and the resulting conclusions related to model-field experiment comparability are reported in this chapter. Supplementary runs were then made in an effort to investigate specific questions related to unique design features of each model, and these are reported in chapters 6 and 7. Lessons learned in setting up and operating the three models are reported in appendix E.

5-2. MODEL RUN PLAN. During the process of developing suitable input data for the three models, it was discovered that unique values (or procedures for arriving at these values) did not exist for a number of the required model inputs and that this problem was shared by all three models. These ambiguities presented a problem with respect to model verification in that attempts to investigate even a relatively small number of these possibilities would have expanded the task beyond manageable proportions. In view of the overall objectives of this study, it appeared that a full investigation of this type would not be necessary. The purpose of the study was to determine whether confidence should be placed in the models' abilities to produce reliable predictions of battlefield intervisibility using model inputs developed a priori from available terrain data. Thus, finding that one or two particular combinations might produce reasonably good model results would be of little interest if the number of possible combinations was large, and the one or two good combinations probably would not be identified in normal model usage. It also appeared that required model inputs that were ambiguous to the study team would be equally ambiguous to most model users and that all reasonably conscientious model users would have about the same problems and successes in arriving at suitable inputs.

a. Basic Model Runs. It was decided that a single "best estimate" for each of these parameters would be developed with the expectation that the model results produced would be representative of those obtained in normal applications of the model. Therefore, three basic runs of each model were

required, one for each of the three field trials. One aspect of this run plan bears comment at this point. One of the three models, DYNTACS, includes in its design probabilistic treatments of certain aspects of elevation and vegetation. Thus, it would seem at first glance that the basic evaluation of DYNTACS should be based upon replication using various initial random number seeds rather than upon single model runs. However, the probabilistic treatment in DYNTACS of these aspects of terrain represents an attempt to conserve computer resources (both computer time and core storage) by handling these physical realities probabilistically when in fact such treatment is not necessary. The assumption underlying this approach is that DYNTACS will represent the actual terrain with reasonable fidelity regardless of the initial random number seed chosen. It was decided that a single random number seed would be used for all three runs and that the sensitivity of DYNTACS results to the random number seed would be investigated in the supplementary runs.

b. Supplementary Model Runs. In addition to the three basic runs, several supplementary runs of two of the models were made in an effort to investigate specific aspects of each model's design. The results of these supplementary runs are reported separately in the two succeeding chapters.

5-3. COMPARISON OF MODEL AND FIELD EXPERIMENT RESULTS. The data produced by the three basic runs of each model were compared to the corresponding field data in several different ways. The results of these comparisons are presented below, with successive subparagraphs devoted to each of these different comparison procedures.

a. Amount of Battlefield Visible. The cumulative length of all the line-of-sight segments for a given site and tactic was computed and is referred to as the amount of battlefield visible. The amount of battlefield visible, expressed in visible kilometers, is an aggregated measure of the intervisible traces along all 10 attacker routes when viewed from all 36 defender positions. It provides a gross indication of the openness or closeness of a particular terrain site. These data are presented for the field experiment and the three models in tables 5-1a, 1b, and 1c. (Because of their length, these tables, as well as tables 5-2 through 5-4, are placed at the end of this chapter.) Differences between the model and field experiment data expressed as a percent of the field experiment data appear in parentheses in these tables. Several observations concerning these data should be made:

(1) The models view the Hunter-Liggett terrain as much more open than is indicated by the field experiment data with the one exception of IUA on Site B.

(2) From these IUA data, it appears that the model might have done reasonably well on Site B. (Subsequent analyses show these data to be highly midleading.)

(3) Both DYNTACS and CARMONETTE overstate total intervisibility on Site B to a far greater degree than on Site A.

(4) All three models indicate that changes in weapon height affect intervisibility to a greater extent than the field data show.

b. Line-of-Sight Segments. From the limited sensitivity testing of the field experiment data base described in appendix B, it was concluded that the line-of-sight segment characterization of intervisibility provided an unstable measure for comparing the models to the field experiment. However, these data do provide some indication of the nature of differences between the models and the field experiment and the extent to which these differences exist.

(1) Mean LOS segment lengths. A summary of the numbers of line-of-sight segments and the mean segment lengths is provided in tables 5-2a, 2b, and 2c. These summary data seem to indicate that the models tend to produce longer line-of-sight segments than were observed in the field. It should also be noted that major disparities exist among all four in terms of the relationship between height combination and the number of LOS segments.

(2) Number of LOS segments. The numbers of line-of-sight segments classified by length of segment and range of initiation are presented for each model in tables 5-3a through 31. (It should be noted that the procedure used throughout the intervisibility study for computing range is considerably different from that used in previous reports on TETAM. For model verification, it was necessary to identify trends with respect to specific areas of the battlefield. Therefore, range was computed as the (shortest) distance from any point on the battlefield to the straight line generally describing the forward edge of the battle area (FEBA).) The numbers of LOS segments from the field experiment corresponding to these model data are shown in parentheses. Data for Site A (Covered Approach) are not included here as they are similar to the Site A (Rapid Approach) data. Several observations concerning these data are appropriate at this point.

(a) The classification of LOS segments into length groupings confirms the earlier impression that all three models tend to produce longer stretches of continuous line of sight than was reported from the field.

(b) In fact, all three models produce far fewer segments shorter than 200 meters and far greater numbers of very long segments (800+ meters) than were recorded during the field experiment.

c. Line-of-Sight Stakes. The most reliable measure upon which to base comparisons between model and field experiment results is the fundamental line-of-sight (YES-NO) data. The most straightforward procedure

for comparing these fundamental LOS data would have been simply to compare and tabulate the number of agreements between the model and field data at each stake from which data were collected. Since only DYNTACS computed LOS data for the exact stake locations used in the field and because it appeared desirable that a single procedure be used for evaluating data from all three models, this simple procedure was not adopted. Instead, the total number of line-of-sight "YES" observations between all stakes and panels were counted and classified according to range band and path for both the model and field data. Because the intervals at which LOS data were produced by IUA and CARMONETTE were greater than the interval used in the field experiment, the number of "YES" observations from each model had to be adjusted by an appropriate factor to make the model data comparable to those from the field. A single factor was used to adjust model data for each site (and tactic), and this factor was defined as the ratio of the total number of LOS observations ("YES" and "NO") from the field experiment to the total number of LOS observations from the model. Specific values for these factors are summarized below:

Site (Tactic)	DYNTACS	IUA	CARMONETTE
Site A (Rapid Approach)	1.00	1.097	4.402
Site A (Covered Approach)	1.00	1.105	4.350
Site B (Rapid Approach)	1.00	1.092	3.606

The adjusted number of LOS "YES" observations from each model classified by range band and path and the corresponding data from the field experiment (shown in parentheses) are presented in tables 5-4a through 41. Again, data for Site A (Covered Approach) are similar to those shown for Site A (Rapid Approach) and are not presented here. Several observations with respect to these data should be made here:

(1) Differences between the model and field data are spread across most of the path-range band classifications.

(2) While the models show more intervisibility than the field experiment in the majority of the classification categories, the opposite is true often enough (particularly on Site A) to indicate that these differences may be attributable to a variety of causes.

(3) Differences on Site A become particularly pronounced at ranges greater than 2,500 meters where all three models show much more intervisibility than is indicated by the field data.

(4) On Site B, both the DYNTACS and CARMONETTE data indicate that, in general, much more can be seen at all ranges than was reported by the field experiment.

(5) IUA results for Site B appear to be erratic in that IUA shows consistently less intervisibility than the field experiment for paths 2, 3, 4, and 5 and consistently more for paths 7, 8, 9, and 10.

5-4. ANALYSIS OF DIFFERENCES. The data presented to this point establish that major differences exist between the results produced by the three models and the field experiment. Although some observations were made concerning general trends in these differences, the data presented were too highly aggregated to support a detailed analysis of differences. Thus, it was necessary to add a third dimension to the classification scheme so that the data would be broken out according to defender weapon position (panel) as well as by path and range band. The basic variable used in this analysis was the total number of stakes on a given path and in a particular (500-meter) range band from which line of sight exists to a specific defender weapon position. (This comparison variable is subsequently referred to as the "number of stakes with LOS" for simplicity.) Since the LOS data were collected from along 10 attacker paths for 36 defender weapon positions and were subsequently classified into 8 arbitrary range bands, a total of 2,880 separate classification categories exist. The number of stakes with LOS from the models were compared to the corresponding data from the field experiment for each of these 2,880 classification categories on each site, and these comparisons formed the basis for the analysis of differences.

a. Categorization of Differences. Differences observed in these 2,880 comparisons were then categorized according to their magnitude using a combination of mathematical and judgmental criteria. Differences between the model and field data were expressed as percentages computed as follows:

$$\text{Percent difference} = \left| \frac{\text{(Number of model stakes with LOS)}}{\text{(Number of field stakes with LOS)}} \right| -1$$

Because there were only about 35 stakes both with and without line of sight in a typical range band on any path, and because often only a few of these were stakes with LOS, it was necessary to complement these percentage computations with some subjective judgments in evaluating the magnitude of observed differences to prevent distortions that result from computing percent differences between two numbers when one (or both) is very small. A summary of the combined criteria used to classify these differences is shown in table 5-5. The tolerance on the number of stakes is expressed to the nearest half stake to provide for comparable treatment of adjusted IUA and CARMONETTE data and unadjusted DYNTACS data.

Table 5-5. Classification of Differences

Magnitude of Difference	Model Predicts Number of Field Experiment Stakes with LOS Within...
Little or No Difference	1.5 stakes or 15 percent of stakes
Moderately Different	2.5 stakes or 30 percent of stakes
Seriously Different	4.5 stakes or 50 percent of stakes
Completely Different	All other possibilities

b. Distribution of Differences. The addition of defender weapon position as the third dimension in the classification scheme provided intervisibility data for specific pairings of defender weapons with particular areas on the battlefield. Thus, comparisons of the model and field data for these 2,880 categories give some indication not only of how much total intervisibility is associated with each specific area of the battlefield but also of whether this intervisibility is associated with the appropriate defender weapons. Figures 5-1a and 1b show the relative frequencies with which differences of varius magnitudes occur for Site A (Rapid Approach). From these data it is obvious that the models and field experiment are in serious conflict at least as often as they are in general agreement when determining the degree to which intervisibility exists between individual defender positions and specific areas of the battlefield. These same data for Site B are presented in figures 5-2a and 2b. The data indicate that disagreement between the field experiment and the DYNTACS and CARMONETTE models is more pronounced on Site B than on Site A and that the "very close--very different" dichotomy persists. Little weight should be placed on the IUA results shown here for reasons that are outlined in subsequent discussion.

c. Other Trends. Two other general trends of differences between the models and field experiment were identified.

(1) Figures 5-3a through 3d show for Sites A and B the relative frequencies of model and field experiment agreement (within 15 percent) as a function of the number of field experiment stakes with LOS. These data show, as one might expect, that the models are more likely to agree when either none or most of the stakes had LOS in the field, and this trend is present on both sites. To some extent, particularly on Site A, these data are the result of a number of situations where it is clear that LOS either does or does not exist. However, the magnitude of this effect might also indicate that the models have more trouble as the terrain scene becomes more complex. Figures 5-3c and 3d show why little

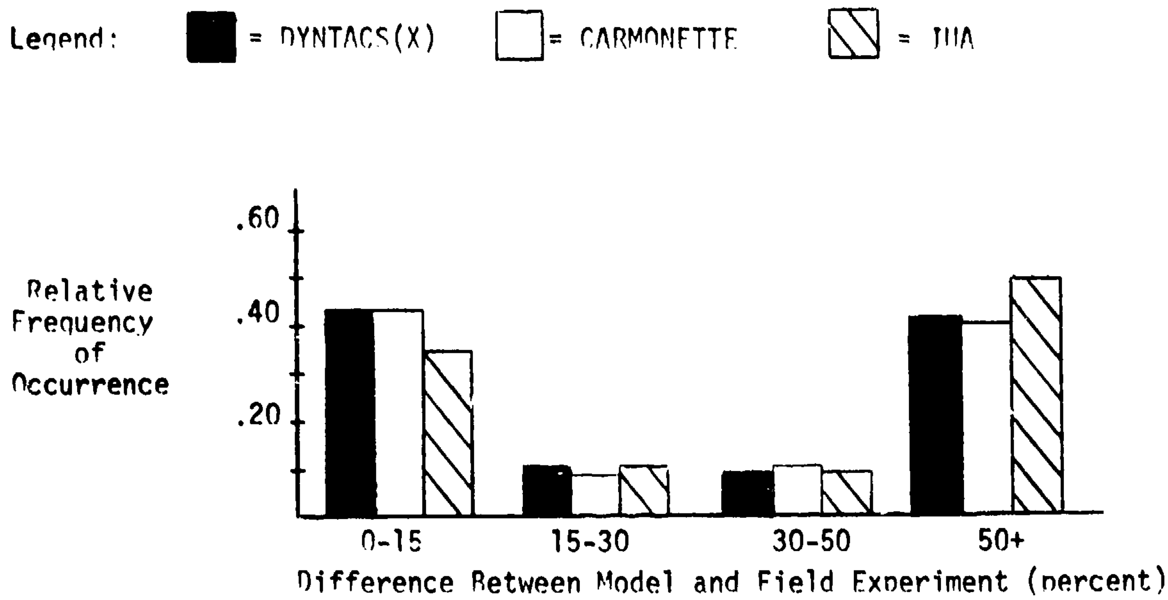

Figure 5-1a. Distribution of Differences Between Each Model and Field Experiment Based upon 2,880 Observed Attacker versus Defender Situations on Site A (Rapid Approach) High Attacker, High Defender

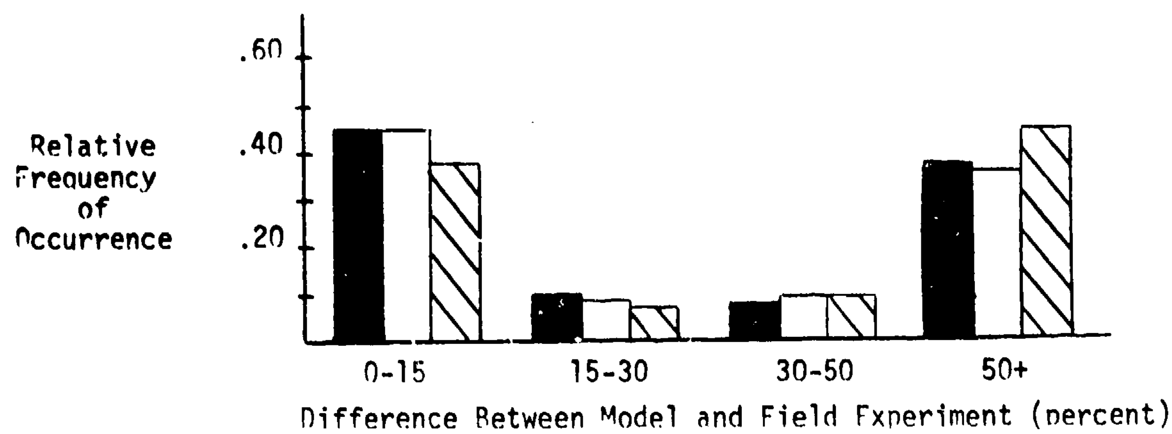

Figure 5-1b. Distribution of Differences Between Each Model and Field Experiment Based upon 2,880 Observed Attacker versus Defender Situations on Site A (Rapid Approach) Low Attacker, Low Defender

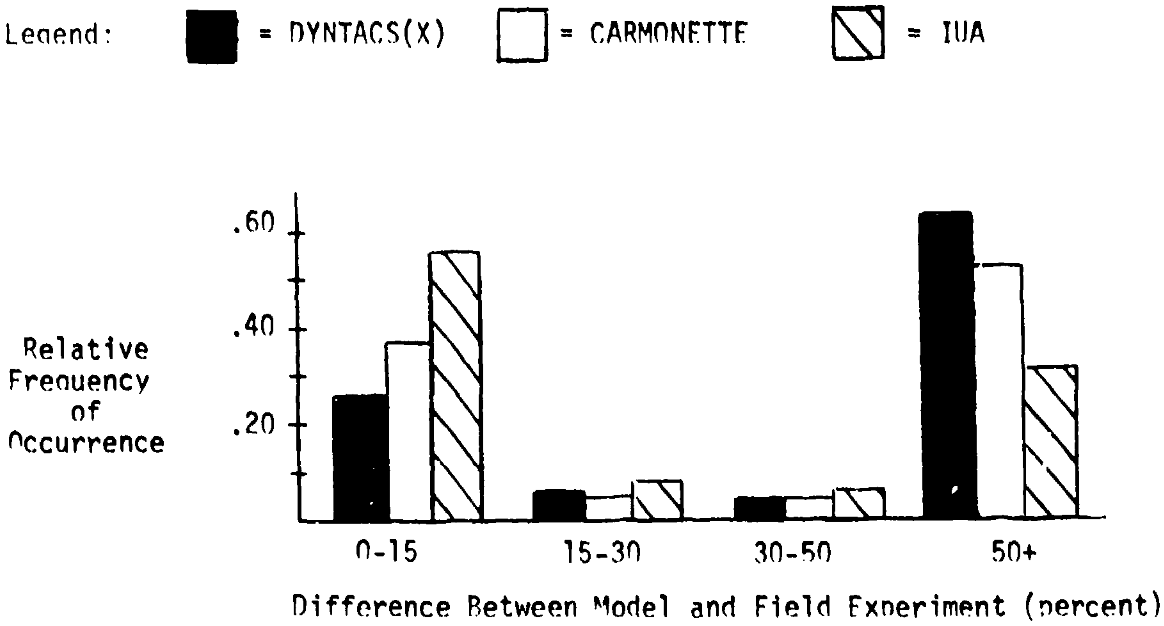

Figure 5-2a. Distribution of Differences Between Each Model and Field Experiment Based Upon 2,880 Observed Attacker versus Defender Situations on Site B (Rapid Approach) High Attacker, High Defender

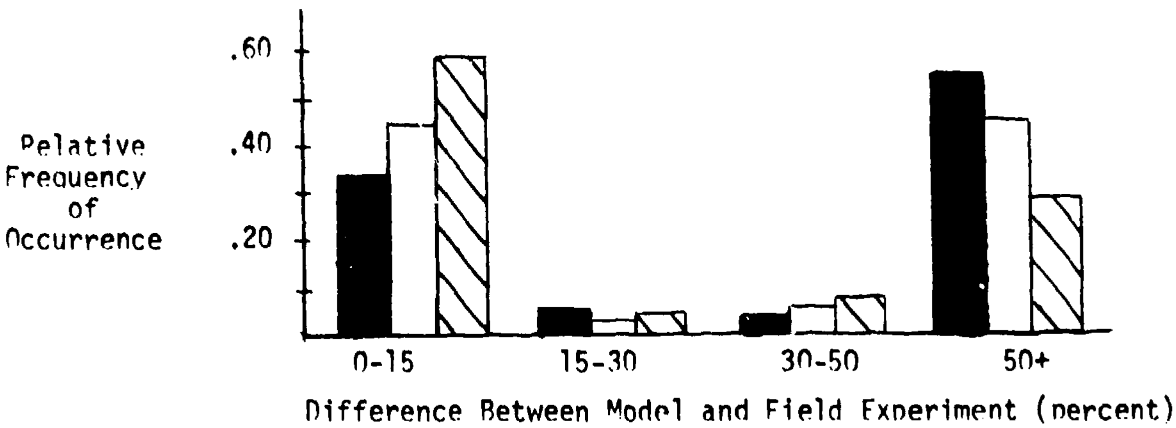

Figure 5-2b. Distribution of Differences Between Each Model and Field Experiment Based upon 2,880 Observed Attacker versus Defender Situations on Site B (Rapid Approach) Low Attacker, Low Defender

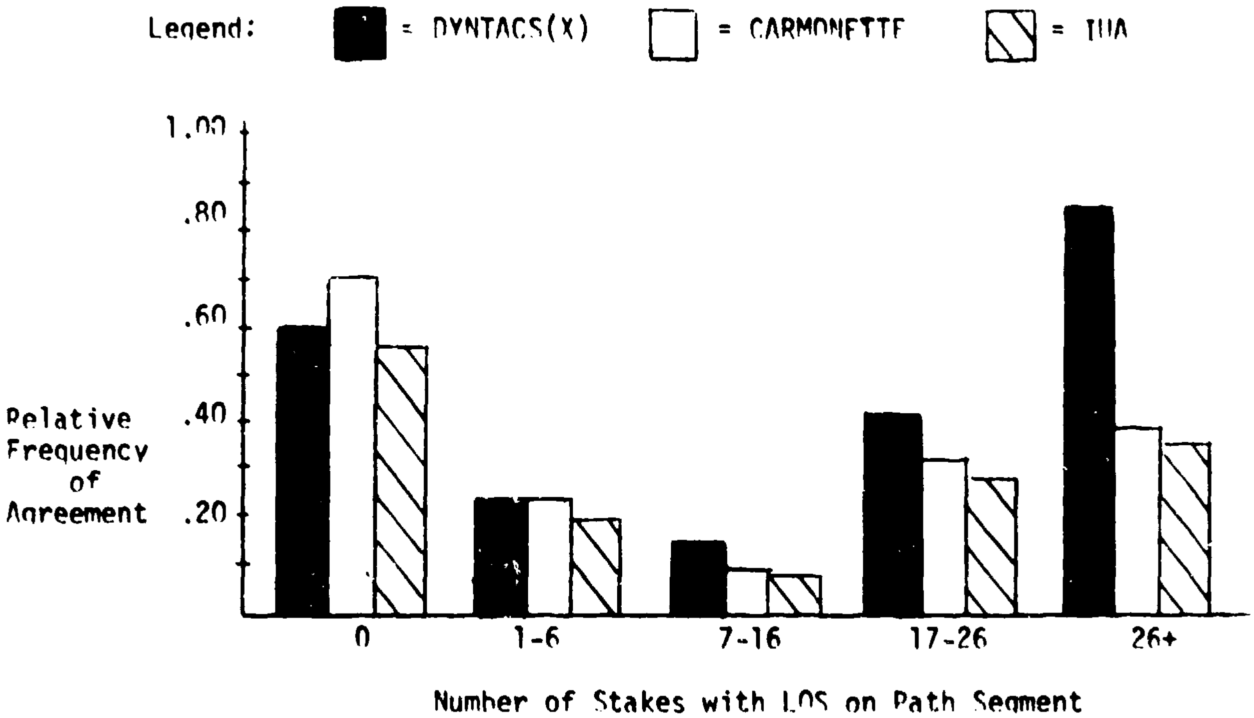

Figure 5-3a. Agreement Between Models and Field Experiment as a Function of Amount of Path Segment Visible in Field Experiment for 2,880 Observed Situations on Site A (Rapid Approach), High Attacker, High Defender

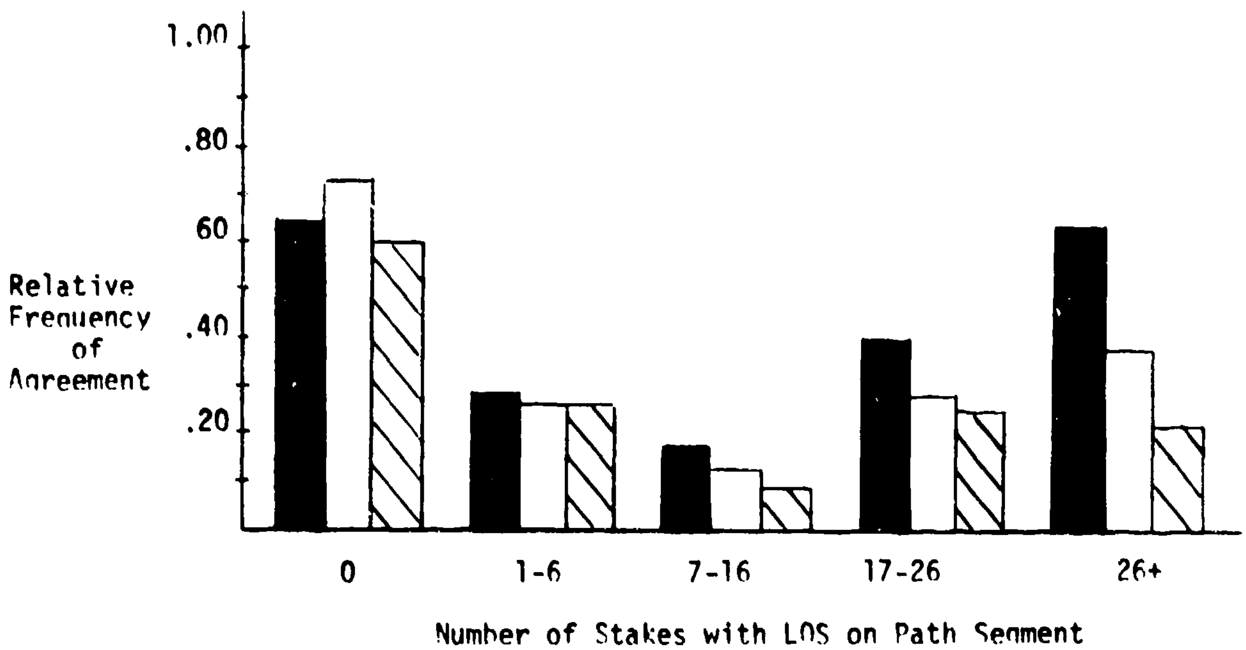

Figure 5-3b. Agreement Between Models and Field Experiment as a Function of Amount of Path Segment Visible in Field Experiment for 2,880 Observed Situations on Site A (Rapid Approach), Low Attacker, Low Defender

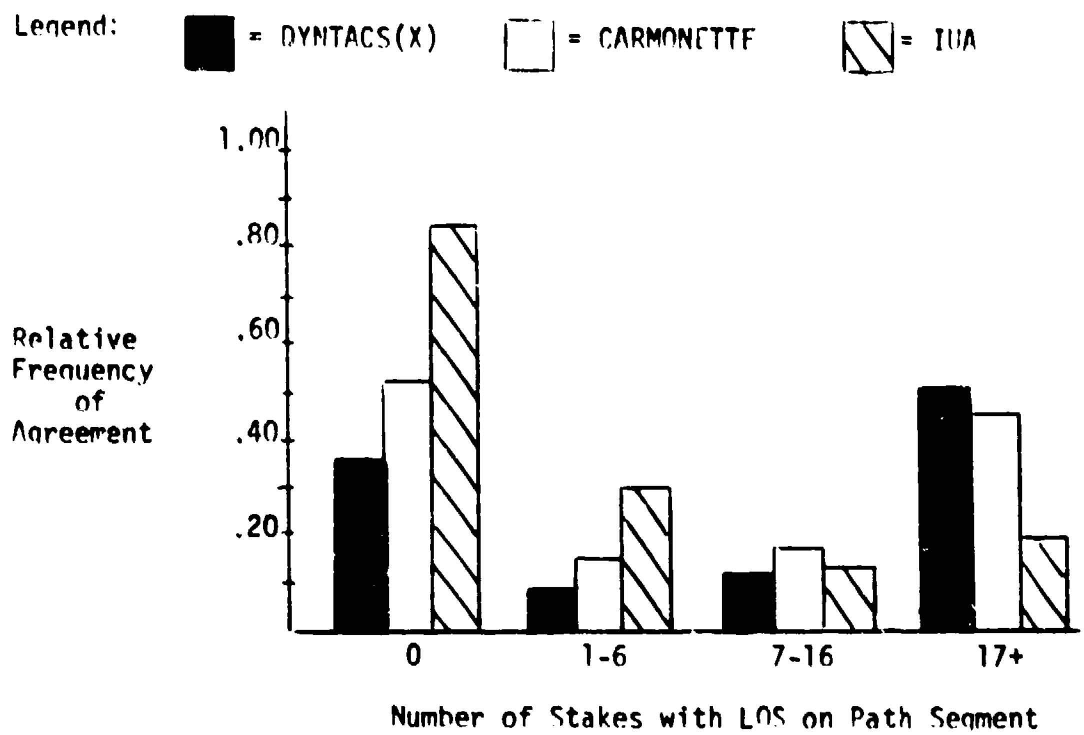

Figure 5-3c. Agreement Between Models and Field Experiment as a Function of Amount of Path Segment Visible in Field Experiment for 2,880 Observed Situations on Site B (Rapid Approach), High Attacker, High Defender

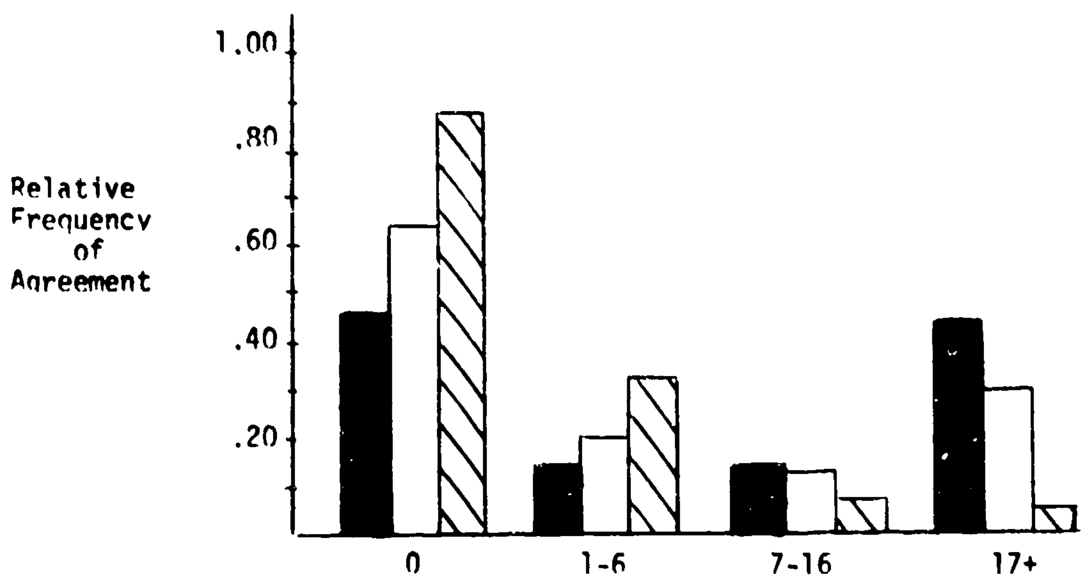

Figure 5-3d. Agreement Between Models and Field Experiment as a Function of Amount of Path Segment Visible in Field Experiment for 2,880 Observed Situations on Site B (Rapid Approach), Low Attacker, Low Defender

weight should be placed on the IUA results for Site B. In addition to the erratic patterns for IUA described earlier in paragraph 3c(5), the preponderance of IUA agreements occur when the field data report that few or no stakes with LOS exist. Where sufficient amounts of LOS exist for the purposes of employing antitank weapons, IUA agrees with the field experiment less than half as often as the other two models.

(2) The one other trend identified from these data is the confirmation of the tendency of all three models to view the terrain generally as more open than indicated by the field data. The data presented in figures 5-4a and 4b show not only that this trend exists in the aggregate but also that in general each of the individual defender weapons tends to "see" more of the battlefield than it should according to the field data.

5-5. SUMMARY OF COMPARISONS. Sufficient control was established over the development of model inputs to insure that reasonable comparisons of model and field experiment results could be accomplished. The models were set up using input data designed to mirror field experiment conditions as closely as possible while at the same time producing model results representative of those realized during typical applications of the models. Three basic runs were made with each model, one corresponding to each of the three trials of the intervisibility field experiment conducted at Hunter-Liggett. The intervisibility data produced by these model runs were then compared to corresponding data collected in the field. These comparisons, performed using several different procedures, resulted in the following principal findings:

a. Major differences exist between the intervisibility conditions recorded in the field experiment and those predicted by all three models. The extent to which these differences exist is obvious regardless of the procedures used for comparing the data.

b. In a typical model run, defensively employed antitank weapons see approximately the "right" amount (i.e., same amount as reported by the field experiment) of specific areas of interest on the battlefield about 40 percent of the time. These same weapons see vastly different amounts of these areas than they should (according to the field data) at least 40 percent of the time as well.

c. There is a strong tendency for the models to predict more intervisibility than was reported by the field experiment. This strong effect is present at all ranges and for most defender (and attacker) weapons.

d. All three models produce substantially longer line-of-sight segments than were observed in the field. Under the presumption that the field data are correct, the implication is that during normal model applications attackers and defenders will be exposed to each other's observations and fires for longer than realistic periods.

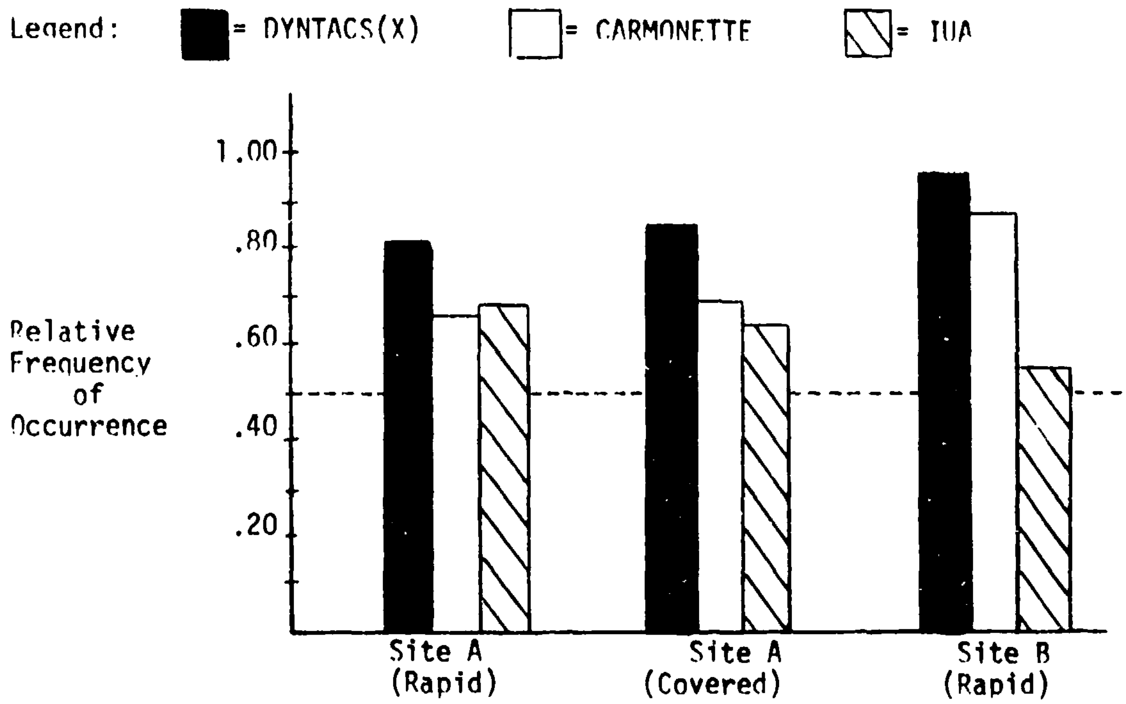

Figure 5-4a. Frequency with Which Models Show Battlefield as More Open Than Reported by Field Experiment, Given That Model and Field Observations Differ by More Than 15 Percent, High Attacker, High Defender

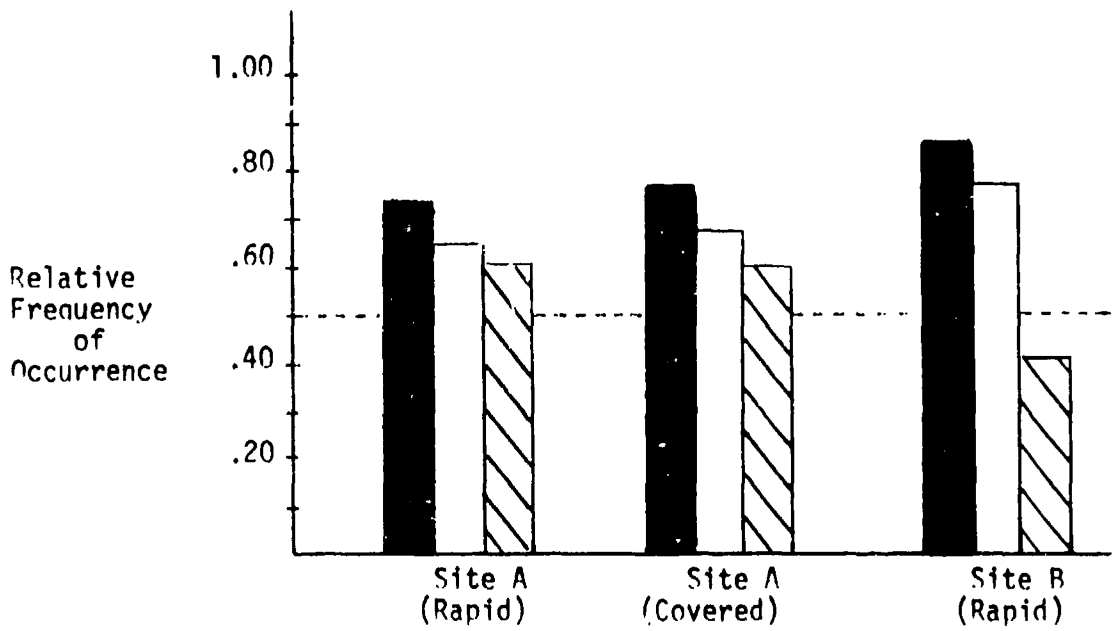

Figure 5-4b. Frequency with Which Models Show Battlefield as More Open Than Reported by Field Experiment, Given That Model and Field Observations Differ by More Than 15 Percent, Low Attacker, Low Defender

e. All three models indicate that intervisibility is affected to a much greater extent by changes in weapon height than is indicated by the field data. It is also worth noting that changes in weapon height change the number of LOS segments in uniquely different ways for the field experiment and for each model.

f. Differences between the model and field experiment data become more pronounced at longer ranges. This divergence becomes noticeable at a range of about 2,500 meters on Site A and 1,500 meters on Site B.

g. The models are most likely to agree with the field experiment (on the extent to which specific defender weapons can see specific areas of the battlefield) in those cases in which the field experiment indicated that either none or almost all of the specific area can be seen.

Table 5-1a. Amount of Battlefield Visible to Defenders on Site A (Rapid Approach)

Attacker Height	Defender Height	Number of "Visible Kilometers"			
		CDEC	DYNTACS(X)	IUA	CARMONETTE
LO	HI	476	747 (+57%)	603 (+27%)	641 (+35%)
LO	MED	473	723 (+53%)	582 (+23%)	629 (+33%)
LO	LO	458	698 (+52%)	568 (+24%)	605 (+32%)
HI	HI	521	873 (+68%)	750 (+44%)	685 (+31%)
HI	MED	518	848 (+64%)	726 (+40%)	675 (+30%)
HI	LO	503	821 (+63%)	710 (+41%)	654 (+30%)

Table 5-1b. Amount of Battlefield Visible to Defenders on Site A (Covered Approach)

Attacker Height	Defender Height	Number of "Visible Kilometers" CDEC	DYNTACS(X)	IUA	CARMONETTE
LO	HI	407	713 (+75%)	486 (+19%)	586 (+44%)
LO	MED	402	689 (+71%)	473 (+18%)	575 (+43%)
LO	LO	392	649 (+66%)	466 (+19%)	553 (+41%)
HI	HI	448	869 (+94%)	601 (+34%)	631 (+41%)
HI	MED	444	843 (+90%)	584 (+32%)	624 (+41%)
HI	LO	433	799 (+85%)	574 (+33%)	602 (+39%)

Table 5-1c. Amount of Battlefield Visible to Defenders on Site B (Rapid Approach)

Attacker Height	Defender Height	Number of "Visible Kilometers" CDEC	DYNTACS(X)	IUA	CARMONETTE
LO	HI	238	732 (+207%)	229 (-4%)	651 (+173%)
LO	MED	230	678 (+195%)	175 (-24%)	613 (+167%)
LO	LO	220	632 (+187%)	161 (-26%)	532 (+142%)
HI	HI	251	868 (+245%)	265 (+5%)	716 (+185%)
HI	MED	246	819 (+233%)	220 (-10%)	675 (+175%)
HI	LO	235	770 (+228%)	195 (-17%)	589 (+151%)

Table 5-2a. Comparison of Line of Sight Segments
Site A (Rapid Approach)

Attacker Height	Defender Height	Number of LOS Segments (Average Segment Length)			
		CDEC	DYNTACS(X)	IUA	CARMONETTE
LO	HI	3003 (158)	3046 (245)	1320 (457)	1275 (503)
LO	MED	2991 (158)	2992 (242)	1284 (453)	1268 (497)
LO	LO	2989 (153)	2919 (239)	1248 (456)	1214 (499)
HI	HI	3009 (173)	2332 (375)	1140 (658)	1250 (548)
HI	MED	3006 (173)	2304 (368)	1116 (651)	1243 (544)
HI	LO	3035 (166)	2230 (368)	1104 (644)	1188 (551)

Table 5-2b. Comparison of Line of Sight Segments
Site A (Covered Approach)

Attacker Height	Defender Height	Number of LOS Segments (Average Segment Length) CDEC	DYNTACS(X)	IUA	CARMONETTE
LO	HI	2898 (140)	3324 (215)	1152 (423)	1301 (450)
LO	MED	2898 (139)	3243 (212)	1122 (422)	1285 (448)
LO	LO	2888 (136)	3140 (207)	1107 (421)	1236 (447)
HI	HI	3155 (142)	2283 (381)	927 (548)	1306 (483)
HI	MED	3142 (141)	2246 (375)	906 (645)	1291 (483)
HI	LO	3133 (138)	2211 (361)	882 (651)	1245 (483)

Table 5-2c. Comparison of Line of Sight Segments
Site B (Rapid Approach)

Attacker Height	Defender Height	Number of LOS Segments (Average Segment Length)			
		CDEC	DYNTACS(X)	IUA	CARMONETTE
LO	HI	2538 (94)	3149 (233)	580 (397)	1355 (481)
LO	MED	2519 (91)	3131 (217)	612 (286)	1301 (472)
LO	LO	2476 (89)	3047 (208)	480 (337)	1178 (452)
HI	HI	2807 (90)	2286 (380)	608 (436)	1341 (534)
HI	MED	2819 (87)	2324 (352)	600 (368)	1291 (523)
HI	LO	2773 (85)	2295 (335)	560 (350)	1187 (497)

Table 5-3a. Number of LOS Segments for Site A (Rapid Approach) DYNTACS vs (CDEC), Hi Attacker, Hi Defender

Length of Segment (meters)	Range at LOS Initiation						Totals
	0-1000	1000-1500	1500-2000	2000-2500	2500-3000	3000+	
0 - 200	402 (589)	254 (523)	201 (475)	225 (390)	122 (109)	163 (285)	1367 (2371)
200 - 400	82 (72)	22 (63)	51 (59)	25 (40)	35 (6)	73 (36)	288 (276)
400 - 800	53 (64	13 (38)	71 (46)	33 (52)	23 (1)	62 (4)	255 (205)
800 - 1600	77 (29)	87 (72)	59 (14)	16 (34)	26 (1)	93 (0)	358 (150)
1600+	0 (0)	0 (1)	25 (3)	0 (3)	6 (0)	33 (0)	64 (7)
Totals	614 (754)	376 (697)	407 (597)	299 (519)	212 (117)	424 (325)	2332 (3009)

Table 5-3b. Number of LOS Segments for Site A (Rapid Approach) DYNTACS vs (CDEC), Low Attacker, Low Defender

Length of Segment (meters)	Range at LOS Initiation						Totals
	0-1000	1000-1500	1500-2000	2000-2500	2500-3000	3000+	
0 - 200	542 (618)	287 (560)	267 (524)	306 (368)	275 (90)	208 (247)	1885 (2407)
200 - 400	86 (77)	43 (67)	73 (54)	52 (46)	56 (0)	81 (18)	391 (262)
400 - 800	81 (69)	17 (27)	102 (54)	73 (42)	58 (0)	94 (9)	425 (201)
800 - 1600	70 (36)	24 (56)	34 (10)	22 (17)	8 (0)	46 (0)	204 (119)
1600+	0 (0)	0 (0)	14 (0)	0 (0)	0 (0)	0 (0)	14 (0)
Totals	779 (800)	371 (710)	490 (642)	453 (473)	397 (90)	429 (274)	2919 (2989)

Table 5-3c. Number of LOS Segments for Site A (Rapid Approach) IUA vs (CDEC), Hi Attacker, Hi Defender

Length of Segment (meters)	Range at LOS Initiation						Totals
	0-1000	1000-1500	1500-2000	2000-2500	2500-3000	3000+	
0 - 200	72 (589)	24 (523)	0 (475)	12 (390)	60 (109)	24 (285)	192 (2371)
200 - 400	60 (72)	60 (63)	0 (59)	72 (40)	48 (6)	72 (36)	312 (276)
400 - 800	120 (64)	0 (38)	48 (46)	36 (52)	12 (1)	60 (4)	276 (205)
800 - 1600	60 (29)	24 (72)	48 (14)	60 (34)	12 (1)	84 (0)	288 (150)
1600+	0 (0)	0 (1)	36 (3)	12 (3)	24 (0)	0 (0)	72 (7)
Totals	312 (754)	108 (697)	132 (597)	192 (519)	156 (117)	240 (325)	1140 (3009)

Table 5-3d. Number of LOS Segments for Site A (Rapid Approach) IUA vs (CDEC), Low Attacker, Low Defender

Length of Segment (meters)	Range at LOS Initiation						Totals
	0-1000	1000-1500	1500-2000	2000-2500	2500-3000	3000+	
0 - 200	228 (618)	60 (560)	0 (524)	36 (368)	84 (90)	84 (247)	492 (2407)
200 - 400	36 (77)	0 (67)	0 (54)	48 (46)	24 (0)	84 (18)	192 (262)
400 - 800	144 (69)	0 (27)	60 (54)	48 (42)	0 (0)	84 (9)	336 (201)
800 - 1600	48 (36)	0 (56)	84 (10)	48 (17)	0 (0)	12 (0)	192 (119)
1600+	0 (0)	0 (0)	0 (0)	36 (0)	0 (0)	0 (0)	36 (0)
Totals	456 (800)	60 (710)	144 (642)	216 (473)	108 (90)	264 (274)	1248 (2989)

Table 5-3e. Number of LOS Segments for Site A (Rapid Approach) CARMONETTE vs (CDEC), Hi Attacker, Hi Defender

Length of Segment (meters)	Range at LOS Initiation						Totals
	0-1000	1000-1500	1500-2000	2000-2500	2500-3000	3000+	
0 - 200	69 (589)	63 (523)	46 (475)	140 (390)	36 (109)	115 (285)	469 (2371)
200 - 400	58 (72)	28 (63)	46 (59)	68 (40)	19 (6)	61 (36)	280 (276)
400 - 800	46 (64)	23 (38)	47 (46)	34 (52)	7 (1)	43 (4)	200 (205)
800 - 1600	51 (29)	39 (72)	47 (14)	54 (34)	0 (1)	35 (0)	226 (150)
1600+	6 (0)	22 (1)	33 (3)	20 (3)	0 (0)	0 (0)	81 (7)
Totals	230 (754)	175 (697)	219 (597)	316 (519)	62 (117)	254 (325)	1256 (3009)

Table 5-3f. Number of LOS Segments for Site A (Rapid Approach) CARMONETTE vs (CDEC), Low Attacker, Low Defender

Length of Segment (meters)	Range at LOS Initiation						Totals
	0-1000	1000-1500	1500-2000	2000-2500	2500-3000	3000+	
0 - 200	81 (618)	65 (560)	58 (524)	145 (368)	22 (90)	105 (247)	476 (2407)
200 - 400	62 (77)	33 (67)	57 (54)	53 (46)	8 (0)	66 (18)	279 (262)
400 - 800	47 (69)	30 (27)	37 (54)	37 (42)	3 (0)	41 (9)	195 (201)
800 - 1600	51 (36)	39 (56)	56 (10)	41 (17)	0 (0)	27 (0)	214 (119)
1600+	0 (0)	21 (0)	17 (0)	12 (0)	0 (0)	0 (0)	50 (0)
Totals	241 (800)	188 (710)	225 (642)	288 (473)	33 (90)	239 (274)	1214 (2989)

Table 5-3g. Number of LOS Segments for Site B (Rapid Approach) DYNTACS vs (CDEC), Hi Attacker, Hi Defender

Length of Segment (meters)	Range at LOS Initiation						Totals
	0-1000	1000-1500	1500-2000	2000-2500	2500-3000	3000+	
0 - 200	389 (1287)	134 (601)	161 (281)	146 (121)	152 (158)	292 (59)	1274 (2507)
200 - 400	43 (91)	14 (46)	27 (16)	21 (17)	61 (22)	39 (6)	205 (198)
400 - 800	146 (57)	41 (17)	103 (5)	11 (6)	82 (4)	158 (1)	541 (90)
800 - 1600	1 (3)	23 (7)	98 (2)	17 (0)	15 (0)	30 (0)	184 (12)
1600+	0 (0)	0 (0)	46 (0)	0 (0)	2 (0)	34 (0)	82 (0)
Totals	579 (1438)	212 (671)	435 (304)	195 (144)	312 (184)	553 (66)	2286 (2807)

Table 5-3h. Number of LOS Segments for Site B (Rapid Approach) DYNTACS vs (CDEC), Low Attacker, Low Defender

Length of Segment (meters)	Range at LOS Initiation						Totals
	0-1000	1000-1500	1500-2000	2000-2500	2500-3000	3000+	
0 - 200	856 (1209)	364 (561)	237 (207)	143 (80)	231 (112)	319 (33)	2150 (2202)
200 - 400	67 (93)	66 (35)	72 (10)	26 (12)	58 (23)	80 (5)	369 (178)
400 - 800	141 (51)	33 (22)	98 (5)	9 (4)	43 (3)	85 (2)	409 (87)
800 - 1600	4 (2)	41 (6)	28 (0)	7 (0)	0 (1)	12 (0)	92 (9)
1600+	0 (0)	0 (0)	13 (0)	3 (0)	4 (0)	7 (0)	27 (0)
Totals	1068 (1355)	504 (624)	448 (222)	188 (96)	336 (139)	503 (40)	3047 (2476)

Table 5-3i. Number of LOS Segments on Site B (Rapid Approach) IUA vs (CDEC), Hi Attacker, Hi Defender

Length of Segment (meters)	Range at LOS Initiation						Totals
	0-1000	1000-1500	1500-2000	2000-2500	2500-3000	3000+	
0 - 200	108 (1287)	36 (601)	0 (281)	0 (121)	64 (158)	20 (59)	228 (2507)
200 - 400	52 (91)	28 (46)	0 (16)	0 (17)	96 (22)	8 (6)	184 (198)
400 - 800	24 (57)	8 (17)	0 (5)	0 (6)	0 (4)	40 (1)	72 (90)
800 - 1600	28 (3)	28 (7)	48 (2)	0 (0)	0 (0)	0 (0)	104 (12)
1600+	0 (0)	0 (0)	20 (0)	0 (0)	0 (0)	0 (0)	20 (0)
Totals	212 (1438)	100 (671)	68 (304)	0 (144)	160 (184)	68 (66)	608 (2807)

Table 5-3j. Number of LOS Segments for Site B (Rapid Approach)
IUA vs (CDEC), Low Attacker, Low Defender

Length of Segment (meters)	Range at LOS Initiation						Totals
	0-1000	1000-1500	1500-2000	2000-2500	2500-3000	3000+	
0 - 200	160 (1209)	8 (561)	0 (207)	28 (80)	64 (112)	0 (33)	260 (2202)
200 - 400	44 (93)	8 (35)	0 (10)	0 (12)	28 (23)	16 (5)	96 (178)
400 - 800	24 (51)	8 (22)	0 (5)	0 (4)	0 (3)	8 (2)	40 (87)
800 - 1600	8 (2)	8 (6)	68 (0)	0 (0)	0 (1)	0 (0)	84 (9)
1600+	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Totals	236 (1355)	32 (624)	68 (222)	28 (96)	92 (139)	24 (40)	480 (2476)

Table 5-3k. Number of LOS Segments for Site B (Rapid Approach) CARMONETTE vs (CDEC), Hi Attacker, Hi Defender

Length of Segment (meters)	Range at LOS Initiation 0-1000	1000-1500	1500-2000	2000-2500	2500-3000	3000+	Totals
0 - 200	94 (1287)	38 (601)	115 (281)	67 (121)	120 (158)	102 (59)	536 (2507)
200 - 400	62 (91)	17 (46)	58 (16)	25 (17)	54 (22)	33 (6)	249 (198)
400 - 800	80 (57)	24 (17)	31 (5)	8 (6)	31 (4)	74 (1)	248 (90)
800 - 1600	33 (3)	61 (7)	68 (2)	2 (0)	21 (0)	30 (0)	215 (12)
1600+	0 (0)	9 (0)	65 (0)	9 (0)	1 (0)	9 (0)	93 (0)
Totals	269 (1438)	149 (671)	337 (304)	111 (144)	227 (184)	248 (66)	1341 (2807)

Table 5-31. Number of LOS Segments, Site B (Rapid Approach) CARMONETTE vs (CDEC), Low Attacker Low Defender

Length of Segment (meters)	Range at LOS Initiation						Totals
	0-1000	1000-1500	1500-2000	2000-2500	2500-3000	3000+	
0 - 200	115 (1209)	57 (561)	107 (207)	55 (80)	99 (112)	60 (33)	493 (2202)
200 - 400	95 (93)	18 (35)	46 (10)	14 (12)	44 (23)	29 (5)	246 (178)
400 - 800	89 (51)	47 (22)	39 (5)	5 (4)	27 (3)	39 (2)	246 (87)
800 - 1600	22 (2)	47 (6)	43 (0)	0 (0)	4 (1)	16 (0)	132 (9)
1600+	0 (0)	4 (0)	50 (0)	2 (0)	0 (0)	5 (0)	61 (0)
Totals	321 (1355)	173 (624)	285 (222)	76 (96)	174 (139)	149 (40)	1178 (2476)

Table 5-4a. Number of Stakes with LOS on Site A (Rapid Approach)
DYNTACS vs (CDEC), Hi Attacker, Hi Defender

Range Band (Meters)	Path Number 1	2	3	4	5	6	7	8	9	10
0-500	83 (72)	53 (45)	121 (73)	428 (338)	532 (337)	323 (255)	371 (338)	434 (382)	513 (489)	557 (394)
500-1000	534 (275)	734 (238)	727 (314)	619 (443)	791 (849)	803 (901)	791 (879)	618 (661)	758 (726)	689 (600)
1000-1500	359 (234)	371 (185)	340 (316)	274 (320)	426 (513)	428 (369)	608 (360)	607 (481)	847 (644)	866 (689)
1500-2000	451 (298)	376 (289)	488 (373)	501 (470)	403 (418)	229 (231)	330 (451)	640 (556)	962 (797)	921 (789)
2000-2500	367 (139)	659 (30)	532 (1)	607 (216)	641 (437)	581 (362)	434 (389)	280 (181)	199 (195)	92 (135)
2500-3000	331 (2)	450 (3)	633 (20)	600 (16)	506 (58)	443 (97)	369 (24)	249 (10)	153 (12)	61 (0)
3000-3500	494 (106)	502 (81)	478 (145)	402 (39)	288 (52)	250 (100)	445 (19)	357 (6)	389 (21)	295 (0)
3500+	413 (144)	407 (117)	409 (220)	364 (63)	15 (59)	9 (0)	204 (4)	176 (0)	220 (0)	227 (0)

Table 5-4b. Number of Stakes with LOS on Site A (Rapid Approach) DYNTACS vs (CDEC), Low Attacker, Low Defender

Range Band (Meters)	Path Number									
	1	2	3	4	5	6	7	8	9	10
0-500	52 (61)	28 (34)	76 (49)	340 (324)	472 (311)	272 (245)	339 (311)	398 (350)	428 (411)	484 (362)
500-1000	400 (230)	568 (189)	551 (262)	429 (375)	581 (778)	602 (812)	688 (796)	555 (612)	723 (683)	638 (596)
1000-1500	259 (212)	279 (220)	236 (284)	182 (266)	299 (496)	364 (334)	521 (298)	549 (429)	739 (548)	815 (634)
1500-2000	336 (288)	265 (204)	341 (340)	406 (372)	304 (381)	181 (228)	279 (377)	556 (528)	905 (662)	847 (700)
2000-2500	288 (123)	499 (17)	444 (1)	518 (181)	517 (338)	470 (332)	378 (316)	191 (161)	125 (109)	61 (99)
2500-3000	132 (0)	297 (2)	487 (12)	444 (12)	425 (29)	329 (69)	267 (11)	137 (29)	54 (7)	14 (0)
3000-3500	435 (87)	438 (54)	416 (130)	333 (39)	101 (29)	115 (102)	352 (11)	179 (1)	288 (6)	227 (0)
3500+	399 (101)	387 (114)	394 (239)	306 (63)	0 (27)	1 (0)	150 (4)	133 (0)	155 (0)	143 (0)

Table 5-4c. Number of Stakes with LOS on Site A (Rapid Approach) IUA vs (CDEC), Hi Attacker, Hi Defender

Range Band (Meters)	Path Number 1	2	3	4	5	6	7	8	9	10
0-500	0 (72)	0 (45)	26 (73)	487 (338)	461 (337)	434 (255)	540 (338)	763 (382)	737 (489)	395 (394)
500-1000	197 (275)	197 (238)	118 (314)	290 (443)	869 (849)	895 (901)	750 (879)	921 (661)	882 (726)	553 (600)
1000-1500	0 (234)	171 (285)	0 (316)	224 (320)	461 (513)	500 (369)	276 (360)	658 (481)	842 (644)	711 (689)
1500-2000	92 (298)	79 (289)	211 (373)	382 (470)	882 (418)	987 (231)	606 (451)	737 (558)	895 (797)	790 (789)
2000-2500	145 (139)	395 (30)	434 (1)	619 (216)	895 (437)	987 (362)	171 (389)	276 (181)	145 (195)	105 (135)
2500-3000	0 (2)	92 (3)	184 (20)	290 (16)	658 (58)	369 (97)	118 (24)	0 (10)	0 (12)	0 (0)
3000-3500	329 (106)	342 (81)	395 (145)	395 (39)	684 (52)	606 (100)	211 (19)	329 (6)	171 (21)	145 (0)
3500+	474 (144)	369 (117)	224 (220)	329 (63)	421 (49)	132 (0)	0 (4)	0 (0)	0 (0)	0 (0)

Table 5-4d. Number of Stakes with LOS on Site A (Rapid Approach) IUA vs (CDEC), Low Attacker, Low Defender

Range Band (Meters)	Path Number 1	2	3	4	5	6	7	8	9	10
0-500	0 (61)	0 (34)	0 (49)	105 (324)	408 (311)	395 (245)	513 (311)	763 (350)	737 (411)	382 (362)
500-1000	66 (230)	39 (189)	105 (262)	105 (375)	645 (778)	632 (812)	487 (796)	645 (612)	658 (683)	79 (596)
1000-1500	0 (212)	0 (220)	0 (284)	132 (266)	382 (496)	448 (334)	250 (298)	606 (429)	632 (548)	684 (634)
1500-2000	53 (288)	66 (204)	158 (340)	342 (372)	829 (381)	974 (228)	592 (377)	711 (528)	869 (662)	750 (700)
2000-2500	145 (123)	290 (17)	382 (1)	579 (181)	856 (338)	908 (332)	145 (316)	197 (161)	105 (109)	79 (99)
2500-3000	0 (0)	39 (2)	66 (12)	105 (12)	382 (29)	158 (69)	39 (11)	0 (29)	0 (7)	0 (0)
3000-3500	197 (87)	250 (54)	316 (130)	355 (39)	513 (29)	553 (102)	158 (11)	250 (1)	132 (6)	79 (0)
3500+	263 (101)	39 (114)	0 (239)	79 (63)	132 (27)	92 (0)	0 (4)	0 (0)	0 (0)	0 (0)

Table 5-4e. Number of Stakes with LOS on Site A (Rapid Approach) CARMONETTE vs (CDEC), Hi Attacker, Hi Defender

Range Band (Meters)	Path Number 1	2	3	4	5	6	7	8	9	10
0-500	101 (72)	57 (45)	75 (73)	506 (338)	445 (337)	414 (255)	401 (338)	453 (382)	502 (489)	0 (394)
500-1000	136 (275)	291 (238)	387 (314)	335 (443)	660 (849)	638 (901)	1211 (879)	929 (661)	726 (726)	295 (600)
1000-1500	348 (234)	343 (285)	409 (316)	546 (320)	379 (513)	335 (369)	616 (360)	696 (481)	678 (644)	678 (689)
1500-2000	304 (298)	317 (289)	467 (373)	313 (470)	392 (418)	700 (231)	740 (451)	762 (556)	1153 (797)	1149 (789)
2000-2500	348 (139)	207 (30)	22 (1)	392 (216)	357 (437)	379 (362)	409 (389)	216 (181)	273 (195)	158 (135)
2500-3000	233 (2)	238 (3)	304 (20)	216 (16)	110 (58)	158 (97)	198 (24)	154 (10)	0 (12)	18 (0)
3000-3500	207 (106)	189 (81)	295 (145)	242 (39)	299 (52)	145 (100)	141 (19)	136 (6)	96 (21)	110 (0)
3500+	0 (144)	132 (117)	0 (220)	0 (63)	66 (49)	66 (0)	66 (4)	66 (0)	66 (0)	66 (0)

Table 5-4f. Number of Stakes with LOS on Site A (Rapid Approach) CARMONETTE vs (CDEC), Low Attacker, Low Defender

Range Band (Meters)	Path Number									
	1	2	3	4	5	6	7	8	9	10
0-500	62 (61)	31 (34)	57 (49)	445 (324)	392 (311)	361 (245)	387 (311)	445 (350)	458 (411)	0 (362)
500-1000	110 (230)	247 (189)	313 (262)	277 (375)	612 (778)	572 (812)	1136 (796)	828 (612)	704 (683)	291 (596)
1000-1500	286 (212)	277 (220)	352 (284)	493 (266)	343 (496)	251 (334)	533 (298)	621 (429)	555 (548)	625 (634)
1500-2000	242 (288)	264 (204)	396 (340)	264 (372)	299 (381)	581 (228)	638 (377)	713 (528)	1087 (662)	1087 (700)
2000-2500	282 (123)	176 (17)	4 (1)	317 (181)	295 (338)	330 (332)	348 (316)	185 (161)	225 (109)	128 (99)
2500-3000	154 (0)	198 (2)	282 (12)	203 (12)	101 (29)	128 (69)	97 (11)	92 (29)	0 (7)	0 (0)
3000-3500	194 (87)	180 (54)	286 (130)	[illegible] (39)	291 (29)	145 (102)	132 (11)	132 (1)	97 (6)	97 (0)
3500+	0 (101)	123 (114)	0 (239)	0 (63)	66 (27)	66 (0)	66 (4)	66 (0)	66 (0)	66 (0)

Table 5-4g. Number of Stakes with LOS on Site B (Rapid Approach) DYNTACS vs (CDEC), Hi Attacker, Hi Defender

Range Band (Meters)	Path Number 1	2	3	4	5	6	7	8	9	10
0-500	640 (174)	894 (359)	964 (502)	787 (412)	684 (513)	719 (391)	501 (248)	477 (249)	0 (0)	436 (111)
500-1000	546 (153)	602 (179)	608 (184)	589 (335)	794 (537)	768 (515)	712 (407)	709 (363)	408 (218)	717 (231)
1000-1500	625 (93)	652 (118)	654 (175)	707 (175)	746 (272)	699 (316)	675 (272)	772 (214)	684 (296)	704 (262)
1500-2000	238 (20)	503 (31)	564 (51)	648 (65)	397 (48)	371 (52)	473 (28)	358 (39)	326 (209)	351 (221)
2000-2500	395 (1)	435 (0)	429 (12)	262 (0)	252 (10)	195 (22)	416 (112)	432 (162)	441 (194)	409 (166)
2500-3000	350 (6)	393 (20)	426 (18)	486 (22)	542 (59)	542 (108)	431 (91)	466 (47)	542 (71)	548 (120)
3000-3500	293 (9)	342 (17)	353 (17)	372 (13)	318 (7)	355 (9)	485 (44)	523 (0)	446 (22)	10 (4)
3500+	0 (0)	8 (0)	11 (13)	0 (1)	3 (0)	16 (0)	157 (0)	101 (0)	111 (0)	0 (0)

Table 5-4h. Number of Stakes with LOS on Site B (Rapid Approach) DYNTACS vs (CDEC), Low Attacker, Low Defender

Range Band (Meters)	Path Number									
	1	2	3	4	5	6	7	8	9	10
0-500	582 (156)	772 (294)	778 (455)	679 (351)	536 (459)	593 (396)	329 (234)	374 (230)	0 (0)	249 (98)
500-1000	517 (149)	493 (154)	454 (165)	431 (352)	593 (484)	575 (551)	551 (392)	591 (293)	380 (222)	641 (181)
1000-1500	543 (115)	587 (137)	490 (151)	559 (191)	524 (308)	580 (274)	571 (245)	658 (160)	589 (242)	574 (123)
1500-2000	120 (14)	263 (16)	360 (43)	350 (63)	228 (38)	238 (53)	321 (22)	237 (25)	179 (172)	223 (87)
2000-2500	180 (2)	193 (0)	275 (3)	174 (0)	203 (1)	169 (4)	212 (106)	310 (156)	286 (196)	269 (76)
2500-3000	264 (1)	292 (14)	326 (20)	345 (26)	322 (54)	305 (90)	270 (72)	301 (25)	339 (49)	374 (92)
3000-3500	238 (9)	250 (6)	250 (17)	241 (5)	190 (7)	227 (3)	234 (47)	312 (0)	265 (1)	7 (4)
3500+	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	37 (0)	29 (0)	79 (0)	0 (0)

Table 5-41. Number of Stakes with LOS on Site B (Rapid Approach) IUA vs (CDEC), Hi Attacker, Hi Defender

Range Band (Meters)	Path Number 1	2	3	4	5	6	7	8	9	10
0-500	214 (174)	118 (359)	148 (502)	140 (412)	131 (513)	489 (391)	428 (248)	371 (249)	0 (0)	349 (111)
500-1000	245 (153)	83 (179)	61 (184)	44 (335)	131 (537)	515 (515)	581 (407)	415 (363)	336 (218)	432 (291)
1000-1500	31 (93)	0 (118)	0 (175)	26 (175)	70 (272)	354 (316)	550 (272)	502 (214)	581 (296)	415 (262)
1500-2000	0 (20)	0 (31)	0 (51)	0 (65)	0 (48)	0 (52)	0 (28)	66 (39)	275 (209)	218 (221)
2000-2500	0 (1)	0 (0)	0 (12)	0 (0)	0 (10)	0 (22)	214 (112)	175 (162)	271 (194)	197 (166)
2500-3000	201 (6)	131 (20)	70 (18)	70 (22)	17 (59)	17 (108)	271 (91)	22 (47)	175 (71)	131 (120)
3000-3500	66 (9)	52 (17)	122 (17)	131 (13)	140 (7)	148 (9)	0 (44)	0 (0)	0 (22)	0 (4)
3500+	0 (0)	0 (0)	0 (13)	0 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

Table 5-4i. Number of Stakes with LOS on Site B (Rapid Approach) IUA vs (CDEC), Low Attacker, Low Defender

Range Band (Meters)	Path Number 1	2	3	4	5	6	7	8	9	10
0-500	166 (156)	118 (294)	148 (455)	140 (351)	131 (459)	210 (396)	192 (234)	245 (230)	0 (0)	44 (98)
500-1000	245 (149)	83 (154)	61 (165)	17 (352)	122 (484)	166 (551)	166 (392)	415 (293)	336 (222)	415 (181)
1000-1500	0 (115)	0 (137)	0 (151)	26 (191)	70 (308)	114 (274)	157 (245)	502 (160)	581 (242)	415 (123)
1500-2000	0 (14)	0 (16)	0 (43)	0 (63)	0 (38)	0 (53)	0 (22)	66 (25)	183 (172)	153 (87)
2000-2500	0 (2)	0 (0)	0 (3)	0 (0)	0 (1)	0 (4)	9 (106)	37 (156)	179 (196)	131 (76)
2500-3000	157 (1)	79 (14)	61 (20)	26 (26)	0 (54)	0 (90)	17 (72)	0 (25)	87 (49)	87 (92)
3000-3500	44 (9)	52 (6)	9 (17)	0 (5)	0 (7)	0 (3)	0 (47)	0 (0)	0 (1)	0 (4)
3500+	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

Table 5-4k. Number of Stakes with LOS on Site B (Rapid Approach) CARMONETTE vs (CDEC), Hi Attacker, Hi Defender

Range Band (Meters)	Path Number 1	2	3	4	5	6	7	8	9	10
0-500	617 (174)	685 (359)	905 (502)	653 (412)	671 (513)	526 (391)	400 (248)	411 (249)	0 (0)	613 (111)
500-1000	447 (153)	425 (179)	335 (184)	375 (335)	573 (537)	498 (515)	609 (407)	544 (363)	317 (218)	563 (291)
1000-1500	519 (93)	516 (118)	458 (175)	444 (175)	458 (272)	519 (316)	559 (272)	624 (214)	588 (296)	317 (262)
1500-2000	155 (20)	285 (31)	375 (51)	417 (65)	429 (48)	472 (52)	339 (28)	325 (39)	285 (209)	400 (221)
2000-2500	94 (1)	115 (0)	224 (12)	32 (0)	137 (10)	151 (22)	242 (112)	224 (162)	130 (194)	417 (166)
2500-3000	303 (6)	328 (20)	296 (18)	90 (22)	234 (59)	216 (108)	332 (91)	429 (47)	508 (71)	707 (120)
3000-3500	180 (9)	137 (17)	252 (17)	253 (13)	263 (7)	285 (9)	256 (44)	256 (0)	343 (22)	0 (4)
3500+	0 (0)	0 (0)	18 (13)	18 (1)	14 (0)	18 (0)	50 (0)	43 (0)	14 (0)	0 (0)

Table 5-41. Number of Stakes with LOS on Site B (Rapid Approach) CARMONETTE vs (CDEC), Low Attacker, Low Defender

Range Band (Meters)	Path Number 1	2	3	4	5	6	7	8	9	10
0-500	591 (156)	591 (294)	782 (455)	591 (351)	505 (459)	425 (396)	321 (234)	343 (230)	0 (0)	559 (98)
500-1000	371 (149)	310 (154)	278 (165)	288 (352)	508 (484)	389 (551)	523 (392)	494 (293)	303 (222)	519 (181)
1000-1500	422 (115)	407 (137)	371 (151)	371 (191)	339 (308)	418 (274)	458 (245)	501 (160)	407 (242)	288 (123)
1500-2000	94 (14)	242 (16)	314 (43)	285 (63)	343 (38)	346 (53)	220 (22)	177 (25)	191 (172)	317 (87)
2000-2500	43 (2)	69 (0)	148 (3)	4 (0)	87 (1)	58 (4)	141 (106)	97 (156)	79 (196)	245 (76)
2500-3000	195 (1)	213 (14)	191 (20)	22 (26)	87 (54)	87 (90)	169 (72)	213 (25)	292 (49)	498 (92)
3000-3500	151 (9)	105 (6)	148 (17)	148 (5)	137 (7)	137 (3)	97 (47)	159 (0)	296 (1)	0 (4)
3500+	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	22 (0)	29 (0)	0 (0)	0 (0)

CHAPTER 6

SIDE ANALYSIS--DYNTACS

6-1 GENERAL. The model runs described in the preceding chapter were considered by the study team to be representative of DYNTACS capabilities in typical applications and therefore sufficient for the purpose of determining whether major differences existed between results obtained from the model and the field experiment. However, during this work a number of interesting questions arose concerning specific aspects of the DYNTACS line-of-sight methodology. In an effort to gain a better understanding of the model itself and to investigate the relative importance of certain specific model assumptions and procedures, several additional runs of the DYNTACS LOS routines were made under varying conditions. The principal reasons for performing each of these additional runs and the findings that resulted are presented in this chapter.

6-2. RANDOM NUMBER SEED. One obvious and very important question concerning the DYNTACS LOS methodology was to determine the degree to which intervisibility is affected by changing the random number seed. In view of the large number of LOS determinations collected during a single model run and the relatively high level of aggregation used in the comparisons, the study team felt that substantial differences in intervisibility ought <u>not</u> to result from changing only the random number seed. Additional model runs were performed and analyzed to determine the sensitivity of intervisibility in DYNTACS to changes in the random number seed.

a. <u>Run Plan</u>. Three additional random number seeds were selected and tested to insure they would produce suitable strings of random numbers. Using these seeds, three additional runs of the DYNTACS LOS routines were performed for the Site A (Rapid Approach) conditions. Thus, a total of four model runs were available for use in evaluating model sensitivity. The initial seeds for each of these runs were as follows:

Replication Number	Random Number Seed
1	1946328857
2	65539
3	524287
4	1638766249

b. <u>Analysis Procedures</u>. Summary data for the four runs are contained in table 6-1. Similarity is noted, particularly for the total amount of battlefield visible. The standard series of statistical tests (described in chapter 4) was applied to these data for all six pairwise combinations of the four runs. The results of these tests are summarized in tables 6-2a and 2b for the number of stakes with LOS and in tables 6-3a and 3b for LOS segments, with the indicated decision of accepting or rejecting the null hypothesis that the runs do not differ. The consideration of

Table 6-1. Summary Results for Four Replications of DYNTACS on Site A (Rapid Approach)

	Height Combination	CDEC Exper	DYNTACS Replication			
			Rep #1	Rep #2	Rep #3	Rep #4
Number of LOS Segments	LO-LO	2989	2919	3143	3128	3221
	HI-HI	3009	2332	2509	2505	2623
Amount of Battlefield Visible (Visible Kilometers)	LO-LO	458	698	691	695	692
	HI-HI	521	873	870	870	868
Mean LOS Segment Length (meters)	LO-LO	153	239	220	222	215
	HI-HI	173	375	347	347	331

Table 6-2a. Summary of Statistical Testing on Stakes with LOS, Site A (Rapid Approach), High Attacker, High Defender

	DYNTACS Replications Compared					
	1 & 2	1 & 3	1 & 4	2 & 3	2 & 4	3 & 4
χ^2 Test Statistic (degrees of freedom) ACCEPT/REJECT, $\alpha = .05$	58.35 (79) ACCEPT	44.96 (79) ACCEPT	34.77 (79) ACCEPT	38.53 (79) ACCEPT	47.57 (79) ACCEPT	22.31 (79) ACCEPT
T-test Statistic (degrees of freedom) ACCEPT/REJECT, $\alpha = .05$	.118 (79) ACCEPT	.086 (79) ACCEPT	.168 (79) ACCEPT	-.047 (79) ACCEPT	.049 (79) ACCEPT	.104 (79) ACCEPT
Sign Test: (-/o/+) (degrees of freedom) ACCEPT/REJECT, $\alpha = .05$	44/3/33 (77) ACCEPT	41/3/36 (77) ACCEPT	34/2/44 (78) ACCEPT	36/5/39 (75) ACCEPT	33/4/43 (76) ACCEPT	30/3/47 (77) ACCEPT

Table 6-2b. Summary of Statistical Testing on Stakes with LOS, Site A (Rapid Approach), Low Attacker, Low Defender

	DYNTACS Replications Compared					
	1 & 2	1 & 3	1 & 4	2 & 3	2 & 4	3 & 4
x^2 Test Statistic (degrees of freedom) ACCEPT/REJECT, α = .05	95.92 (63) REJECT	94.06 (69) REJECT	64.26 (69) ACCEPT	82.39 (69) ACCEPT	117.62 (69) REJECT	82.84 (69) ACCEPT
T-test Statistic (degrees of freedom) ACCEPT/REJECT, α = .05	.216 (53) ACCEPT	.126 (69) ACCEPT	.202 (69) ACCEPT	-.093 (69) ACCEPT	-.035 (69) ACCEPT	.049 (69) ACCEPT
Sign Test: (-/o/+) (degrees of freedom) ACCEPT/REJECT, α = .05	26/1/37 (63) ACCEPT	31/1/38 (69) ACCEPT	32/2/36 (68) ACCEPT	39/1/30 (69) ACCEPT	38/0/32 (70) ACCEPT	37/1/32 (69) ACCEPT

Table 6-3a. Summary of Statistical Testing on LOS Segments, Site A (Rapid Approach), High Attacker, High Defender

	DYNTACS Replications Compared					
	1 & 2	1 & 3	1 & 4	2 & 3	2 & 4	3 & 4
χ^2 Test Statistic (degrees of freedom) ACCEPT/REJECT, $\alpha = .05$	61.42 (23) REJECT	30.54 (23) ACCEPT	40.80 (23) REJECT	42.89 (23) REJECT	46.27 (23) REJECT	37.62 (23) REJECT
T-test Statistic (degrees of freedom) ACCEPT/REJECT, $\alpha = .05$	-.212 (23) ACCEPT	-.334 (23) ACCEPT	-.408 (23) ACCEPT	.007 (23) ACCEPT	-.208 (23) ACCEPT	-.219 (23) ACCEPT
Sign Test: (-/o/+) (degrees of freedom) ACCEPT/REJECT, $\alpha = .05$	13/0/11 (24) ACCEPT	13/0/11 (24) ACCEPT	13/1/10 (23) ACCEPT	13/1/10 (23) ACCEPT	11/2/11 (22) ACCEPT	13/0/11 (24) ACCEPT

Table 6-3b. Summary of Statistical Testing on LOS Segments, Site A (Rapid Approach), Low Attacker, Low Defender

	DYNTACS Replications Compared					
	1 & 2	1 & 3	1 & 4	2 & 3	2 & 4	3 & 4
X^2 Test Statistic (degrees of freedom) ACCEPT/REJECT, α = .05	41.49 (17) REJECT	24.40 (17) ACCEPT	109.65 (23) REJECT	28.12 (17) REJECT	129.63 (23) REJECT	102.36 (23) REJECT
T-test Statistic (degrees of freedom) ACCEPT/REJECT, α = .05	-.421 (17) ACCEPT	-.494 (17) ACCEPT	-.253 (23) ACCEPT	.041 (17) ACCEPT	-.087 (23) ACCEPT	-.107 (23) ACCEPT
Sign Test: (-/o/+) (degrees of freedom) ACCEPT/REJECT, α = .05	12/0/6 (18) ACCEPT	12/0/6 (18) ACCEPT	11/0/13 (24) ACCEPT	7/0/11 (18) ACCEPT	11/0/13 (24) ACCEPT	11/1/12 (23) ACCEPT

number of stakes provides an indication of change in the fundamental distribution of LOS "YES" data over the experimentation site, while the segment data are indicators of change in actual patterns of LOS (the extent to which stakes with LOS occur consecutively).

c. Results. From these data, the following findings related to model sensitivity to random number seed resulted:

(1) Varying the choice of random number seed produces observable changes in intervisibility results for DYNTACS at Hunter-Liggett. Whether these differences are of sufficient magnitude to have operational signi-ficiance is not clear. These changes are more pronounced for the lower height combination.

(2) One would expect this effect to be more pronounced in very rough terrain than in smooth terrain. In light of the fact that the experimentation sites at Hunter-Liggett are relatively flat (hence the estimates of microterrain standard deviations input to the model were small), it is possible that the effect of random number seed on intervisi-bility in normal model applications (e.g., in Europe where microterrain standard deviations are likely to be larger) could be significant in an operational sense.

(3) The implication is that variations in terrain makeup can be introduced by the random number from replication to replication and that terrain may be an uncontrolled factor in some DYNTACS applications.

6-3. DIRECTION OF DIAGONALS. The general surface of the battlefield in DYNTACS (the macroterrain surface) is formed by triangular elevation planes established from the uniformly spaced elevation data used in the model. This macroterrain surface is formed by assuming that these tri-angular planes should be established as shown in figure 6-1.

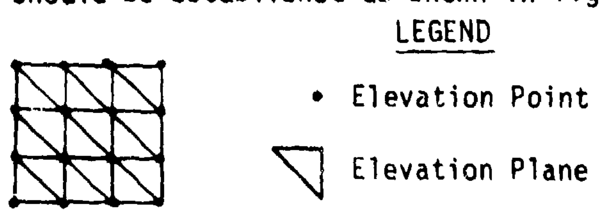

Figure 6-1. Formation of the DYNTACS Macroterrain Surface

The pitfalls in establishing elevation planes through an arbitrary pro-cedure of this nature are illustrated in figures 6-2a and 2b.

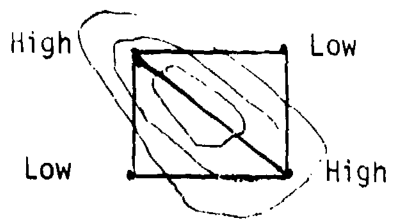

Figure 6-2a. DYNTACS Terrain

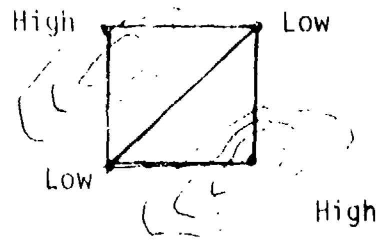

Figure 6-2b. Actual Terrain

The arbitrary procedure used in DYNTACS will always represent the situation shown in figure 6-2a while the actual terrain might look like that shown in figure 6-2b. The DYNTACS design assumes that the interval between elevation points will be selected such that the effects of the phenomenon shown in figures 6-2a and 2b are not significant. If the interval normally used in DYNTACS work meets this criterion, then reversing the direction of these arbitrarily established diagonals should not affect results. Further, in a typical model application, the actual DYNTACS grid is normally rotated so as to provide the greatest amount of flexibility to the gamers in portraying the tactical situation under study. Thus, the angle between the diagonals in the DYNTACS grid and the direction of attacker movement can assume any value. An assumption implicit in this procedure is that intervisibility between attackers and defenders will not be altered significantly by the direction in which these diagonals are arbitrarily established. For these reasons, the DYNTACS LOS routines were modified so that these diagonals were established from upper right to lower left in each grid rather than in the normal direction.

a. Run Plan. The purpose of this investigation was to determine whether changing the direction of these diagonals would have a significant effect on intervisibility. One additional model run was made for the Site A (Rapid Approach) conditions using the random number seed from the basic model run (Replication #1).

b. Analysis Procedure. Because changing the direction of the diagonals alters the random number sequence, the random number was not controlled for this run in the strict sense. Thus, the additional model run was compared to all four of the replications described previously. The summary data in table 6-4 indicate that changing these diagonals from a direction generally parallel to attacker movement to one generally perpendicular to this movement reduces total intervisibility by 7 to 15 percent depending on height combination. The results of statistical testing on stakes with LOS and LOS segments are summarized in tables 6-5a and 5b and tables 6-6a and 6b, respectively.

Table 6-4. Summary Results for Four Replications of DYNTACS and One DYNTACS Run with Diagonals Reversed, for Site A (Rapid Approach)

	Height Combination	CDEC Exper	DYNTACS Diagonals Reversed	Ranges for Four DYNTACS Replications
Number of LOS Segments	LO - LO HI - HI	2989 3009	2950 2294	2919 - 3221 2332 - 2623
Amount of Battlefield Visible ("Visible Kilometers")	LO - LO HI - HI	458 521	589 808	691 - 698 868 - 873
Mean LOS Segment Length (meters)	LO - LO HI - HI	153 173	200 352	215 - 239 331 - 375

Table 6-5a. Summary of Statistical Testing on Stakes with LOS, Site A (Rapid Approach), High Attacker, High Defender

	DYNTACS With Reversed Diagonals vs ...			
	Rep #1	Rep #2	Rep #3	Rep #4
x^2 Test Statistic (degrees of freedom) ACCEPT/REJECT, α = .05	103.39 (71) REJECT	131.49 (71) REJECT	133.56 (71) REJECT	144.73 (71) REJECT
T-test Statistic (degrees of freedom) ACCEPT/REJECT, α = .05	1.191 (71) ACCEPT	0.899 (71) ACCEPT	0.953 (71) ACCEPT	0.891 (71) ACCEPT
Sign Test: (-/o/+) (degrees of freedom) ACCEPT/REJECT, α = .05	2/0/70 (72) REJECT	7/0/65 (72) REJECT	6/0/66 (72) REJECT	8/1/63 (72) REJECT

Table 6-5b. Summary of Statistical Testing on Stakes with LOS, Site A (Rapid Approach), Low Attacker, Low Defender

	DYNTACS With Reversed Diagonals vs ...			
	Rep #1	Rep #2	Rep #3	Rep #4
χ^2 Test Statistic (degrees of freedom) ACCEPT/REJECT, α = .05	123.74 (63) REJECT	152.90 (63) REJECT	148.32 (63) REJECT	187.53 (63) REJECT
T-test Statistic (degrees of freedom) ACCEPT/REJECT, α = .05	1.220 (63) ACCEPT	1.137 (63) ACCEPT	1.111 (63) ACCEPT	1.146 (63) ACCEPT
Sign Test: (-/o/+) (degrees of freedom) ACCEPT/REJECT, α = .05	1/2/61 (62) REJECT	5/0/59 (64) REJECT	3/1/60 (63) REJECT	7/0/57 (64) REJECT

Table 6-6a. Summary of Statistical Testing on LOS Segments, Site A (Rapid Approach), High Attacker, High Defender

	DYNTACS With Reversed Diagonals vs ...			
	Rep #1	Rep #2	Rep #3	Rep #4
χ^2 Test Statistic (degrees of freedom) ACCEPT/REJECT, α = .05	25.12 (23) ACCEPT	59.48 (23) REJECT	28.66 (23) ACCEPT	46.76 (23) REJECT
T-test Statistic (degrees of freedom) ACCEPT/REJECT, α = .05	.102 (23) ACCEPT	.257 (23) ACCEPT	.392 (23) ACCEPT	.438 (23) ACCEPT
Sign Test: (-/o/+) (degrees of freedom) ACCEPT/REJECT, α = .05	10/2/12 (22) ACCEPT	10/2/12 (22) ACCEPT	11/2/11 (22) ACCEPT	7/2/15 (22) ACCEPT

Table 6-6b. Summary of Statistical Testing on LOS Segments, Site A (Rapid Approach), Low Attacker, Low Defender

	DYNTACS With Reversed Diagonals vs ...			
	Rep #1	Rep #2	Rep #3	Rep #4
X^2 Test Statistic (degrees of freedom) ACCEPT/REJECT, α = .05	113.80 (23) REJECT	70.95 (17) REJECT	49.93 (17) REJECT	124.71 (23) REJECT
T-test Statistic (degrees of freedom) ACCEPT/REJECT, α = .05	-.038 (23) ACCEPT	.314 (17) ACCEPT	.305 (17) ACCEPT	.255 (23) ACCEPT
Sign Test: (-/o/+) (degrees of freedom) ACCEPT/REJECT, α = .05	9/1/14 (23) ACCEPT	4/1/13 (17) REJECT	5/2/11 (16) ACCEPT	11/1/12 (23) ACCEPT

c. Results. The following findings resulted from this investigation:

(1) Changing the direction of DYNTACS diagonals from one generally parallel to the direction of attacker movement to one generally perpendicular to this movement results in a substantial reduction in the amount of intervisibility between attacker and defender elements for the terrain investigated.

(2) This change also produces a pronounced shift in the distribution of intervisibility across the battlefield.

6-4. SUMMARY. The two specific aspects of the DYNTACS LOS methodology investigated were model sensitivity to the random number seed and to the directions in which the diagonals of elevation triangles are established. These investigations revealed that changes in the random number seed did produce observable changes in representation of intervisibility on Site A for the low height combinations. Whether these differences would be significant in an operational sense is not known. It was also learned that significant and systematic changes in intervisibility can be introduced by the widely practiced arbitrary rotation of the DYNTACS battlefield.

CHAPTER 7

SIDE ANALYSIS--IUA

7-1. GENERAL. As was the case with the basic DYNTACS runs, the IUA model runs described in chapter 5 were believed to be representative of LOS results achieved in typical applications of the model and therefore sufficient for giving a reasonable indication of model capabilities. However, during the model preparation work, it became obvious that all three models required some subjectivity to be introduced during the preparation of model inputs, and IUA appeared to be particularly bad in this respect. It appeared likely that even slight changes in some of these subjective parameters in IUA would have a drastic effect on LOS results. For this reason, some additional investigations of the IUA model were pursued. The principal reasons for performing these investigations and the findings that resulted are presented in this chapter.

7-2. TERRAIN CODING. A major area of concern requiring further investigation was the handcoded terrain data base for IUA. Relatively minor changes in defender weapon elevations appear to have pronounced effects on intervisibility in both the field data and the model results. It appeared reasonable to expect that variations inherent in the subjective procedures for coding the IUA terrain data might be significant. In an attempt to determine the model's sensitivity to small changes in the terrain data and to assess in both relative and absolute terms the suitability of the coded terrain, several checks on the terrain data were made.

a. Elevation Checks. In an effort to determine the accuracy with which IUA represented elevations within the defender position on Site A, the elevations of the 36 defender weapons as computed by the model were compared to corresponding elevations taken from the 1/25,000 military mapsheet. This comparison revealed that differences in elevations ranged from 0 to 28 meters. The mean difference for the 36 positions was 9.8 meters, and the median was 8 meters. In view of the fact that in the field experiment data observable differences in intervisibility often resulted between height combinations where the elevation change is less than 2 meters, it appeared that terrain data in the vicinity of the defender position on Site A was of unacceptable resolution.

b. Terrain Resolution. The IUA results discussed in chapter 5 were sufficiently different from those of DYNTACS and CARMONETTE to indicate that the IUA terrain data might have been of insufficient resolution over the entire experimentation site as well as in the vicinity of the Site A defensive area. For this reason, the resolution of the Hunter-Liggett terrain data was evaluated in two ways.

(1) First, in an effort to evaluate the adequacy of terrain resolution in relative terms, the triangle size used to represent the Hunter-Liggett terrain was compared with the three terrain areas used for most IUA study applications--the Fulda sites prepared by Lockheed Corporation for the TATAWS study. The results of this comparison are summarized in table 7-1. These data by themselves are of limited value unless used in conjunction with an estimate of the required terrain resolution on each of these sites. However, based upon a subjective comparison of mapsheets of the Fulda and Hunter-Liggett areas, it appears that the resolution of the Hunter-Liggett terrain data was at least as good as that used in previous model applications.

Table 7-1. IUA Terrain Resolution for Hunter-Liggett and Fulda Areas

	Terrain Area			
	HLMR	Fulda 101	Fulda 102	Fulda 103
Number of Triangles	500	431	524	299
Size of Battlefield (in kilometers)	2½x7½	5x8	5x10	5x8
Mean Area per Triangle (square meters)	36,800	49,800	50,500	72,600

(2) Second, in an effort to evaluate the sufficiency of resolution of the HLMR terrain data, using the yardstick of resolution required, the terrain data prepared for IUA were compared visually with aerial photos of the experimentation sites. This comparison indicated that insufficient attention had been paid to vegetation during the coding of the terrain triangles; and, therefore, the IUA terrain data provided a relatively poor representation of the large trees scattered throughout the experimentation site. Thus, while the terrain data were probably at least as good as those used in IUA in the past, in an absolute sense it is likely that these data provided a relatively poor description of the actual Hunter-Liggett terrain.

7-3. PLACEMENT OF OBJECTIVE POINTS. The placement of route and axis objective points was a second matter of major concern because IUA computes line of sight from points along the attacker routes to the objective points rather than to specific defender weapons. All defender weapons in the vicinity of these objective points are then assumed to have the same fields of observation and fire as the objective points. Assuming that accurate representation of intervisibility between attacker

and defender elements on the battlefield is a precondition to acceptable simulation of tank-antitank warfare, then the IUA procedure for computing line of sight is unacceptable for two reasons.

a. First, it is obvious from the magnitude of the changes in intervisibility that result from relatively small changes in defender location that changes in the placement of objective points can have a drastic effect on intervisibility. Because these objective points are assigned subjectively (and without benefit of definitive assignment criteria), drastic differences in intervisibility can be expected between parallel attempts to portray the same tactical plan.

b. Second, the assumption underlying this procedure for computing LOS implies that defender weapons are only rarely employed against attacker weapons approaching on routes other than the one to which that defender weapon is assigned. The assumption is implicit in the IUA methodology because computations made to determine LOS conditions between a specific defender weapon and attacker weapons on other routes and axes are made to points within the defensive position that often are not even in the general vicinity of that defender weapon. This problem is particularly pronounced for defensive positions similar to the one for Site A where the difference in elevation between the highest and lowest defender weapons is nearly 100 meters.

7-4. MODEL RUN PLAN. It was decided that supplementary model runs were necessary to determine whether substantial improvements in model results could be realized by correcting these two serious problems. However, due to the seriousness of both problems, there appeared to be no reliable way of evaluating a promising solution to one without also including a solution for the other in the same model run. Therefore, only one additional model run was made and that run included both individual weapon-to-weapon computations of intervisibility and improved terrain resolution throughout the defensive position on Site A. (Improved terrain resolution was limited to the defensive position, however.) The Site A (Rapid Approach) conditions were selected for the supplementary run.

7-5. ANALYSIS OF RESULTS. To determine whether substantive improvements had been achieved, it was necessary to compare the results of this supplementary model run to both field experiment data and data from the previous IUA run. Summary data for the three are shown in table 7-2. More detailed comparisons illustrating the effect of these model and data changes are presented in figures 7-1a and 1b and 7-2a and 2b.

7-6. FINDINGS. This investigation resulted in the following supplementary findings with respect to the IUA model.

a. When LOS is computed on a weapon-to-weapon basis and the terrain resolution (only) in the vicinity of the defender weapon positions is improved on Site A, a substantial increase is noted in agreement between model and field experiment results.

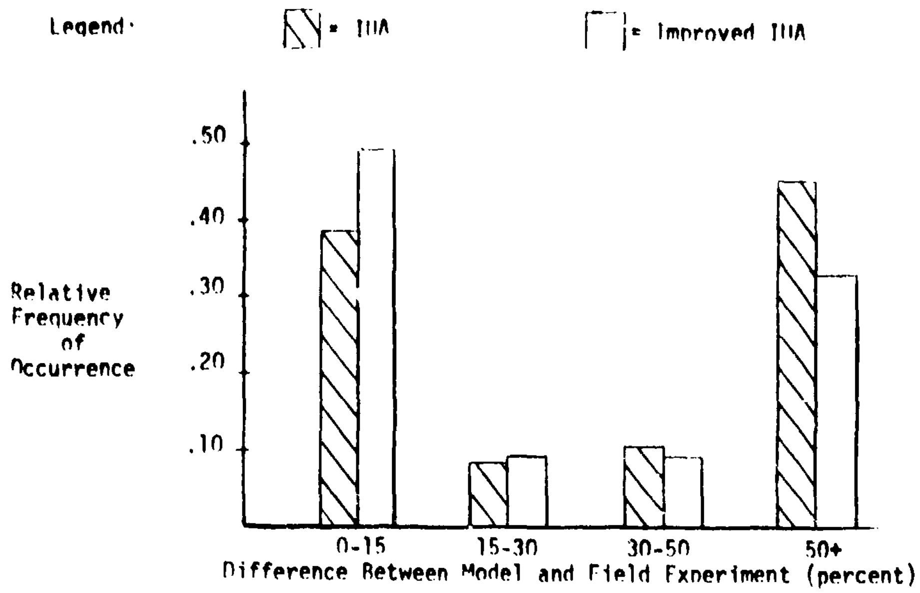

Figure 7-1a. Distribution of Differences Between Improved IUA and Field Experiment Based upon 2,880 Observed Attacker versus Defender Situations on Site A (Rapid Approach), High Attacker, High Defender

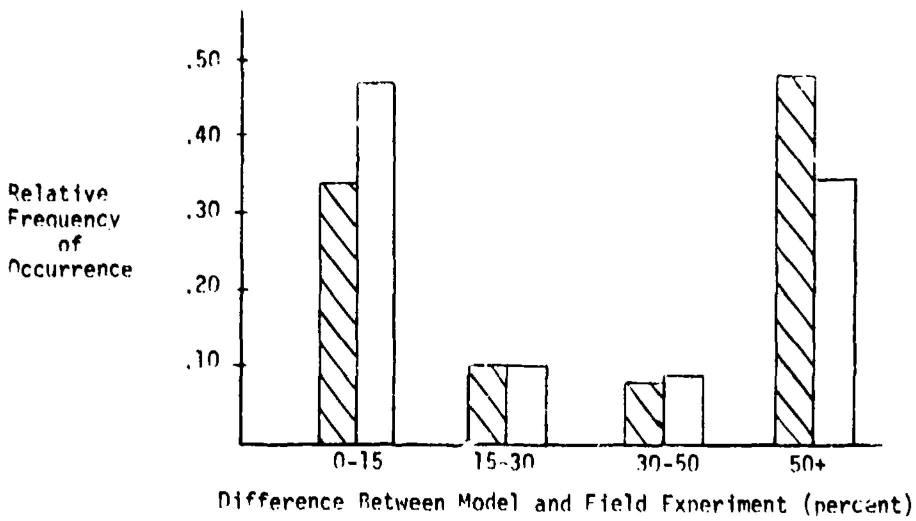

Figure 7-1b. Distribution of Differences Between Improved IUA and Field Experiment Based Upon 2,880 Observed Attacker versus Defender Situations on Site A (Rapid Approach), Low Attacker, Low Defender

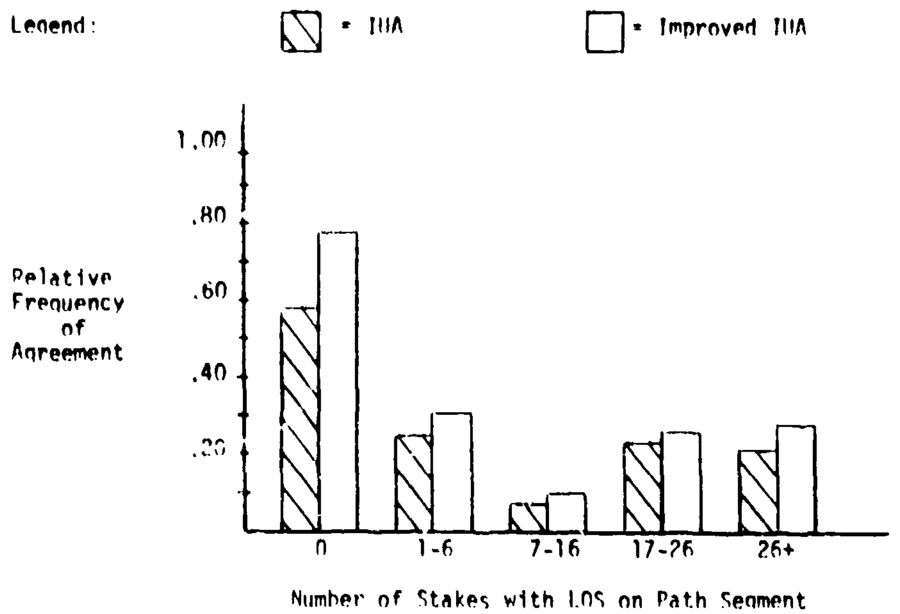

Figure 7-2a. Agreement Between IUA and Field Experiment as a Function of Amount of Path Segment Visible in Field Experiment for 2,880 Observed Situations on Site A (Rapid Approach), High Attacker, High Defender

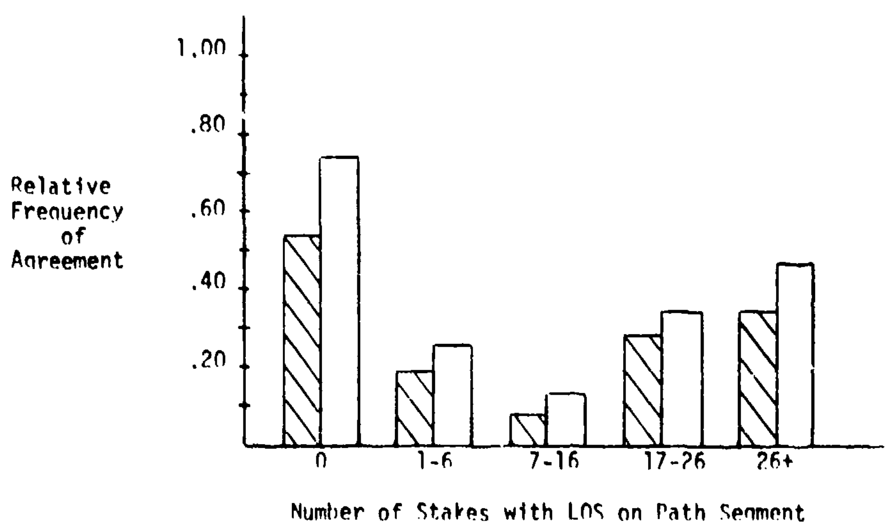

Figure 7-2b. Agreement Between IUA and Field Experiment as a Function of Amount of Path Segment Visible in Field Experiment for 2,880 Observed Situations on Site A (Rapid Approach), Low Attacker, Low Defender

Table 7-2. Summary Results for IUA Improvements on Site A (Rapid Approach)

	Attacker/ Defender Height	CDEC Exper	Regular IUA	Improved IUA
Number of LOS Segments	LO - LO HI - HI	2989 3009	1248 1140	1119 1113
Amount of Battlefield Visible	LO - LO HI - HI	458 521	568 750	436 586
Mean LOS Segment Length	LO - LO HI - HI	153 173	456 658	386 527

b. Because this marked improvement was realized within the constraint of only limited improvement in the terrain representation, further improvement in terrain representation is likely to further improve model results.

7-7. SUMMARY. Two major obstacles to achieving good results with the IUA model were identified and investigated. Model structure was modified in order to provide for weapon-to-weapon computations of LOS, and selective improvements in the terrain data base were added. A model run was then made to determine how this combination of improvements would affect model results. It was found that these two improvements produced substantially increased agreement between model and field experiment results.

CHAPTER 8

FINDINGS AND CONCLUSIONS

8-1. GENERAL. The purpose of this chapter is to identify the principal findings of the intervisibility comparisons, to identify the possible explanations for the differences observed, and to present the conclusions derived from these findings.

8-2. APPLICABILITY. Preparation of the three models included the development of model inputs comparable to those of the field experiment and integration of the model modifications necessary for extracting the appropriate outputs for comparison. The subsequent model runs produced (1) intervisibility data for conditions similar to those reported for the field experiment and (2) results representative of model capabilities in typical applications.

8-3. PRINCIPAL FINDINGS. Intervisibility data produced by each of the three models were compared to corresponding data from the field experiment using several different methods. The following findings resulted from these comparisons:

a. Model and field experiment results were different for all three sets of field experiment conditions, with the models tending to view the Hunter-Liggett experimentation sites as providing conditions generally more favorable for target acquisition and engagement than was reported by the field experiment.

b. These comparisons showed IUA results to be erratic on Site B. These erratic results, which may be representative of past IUA (and Bonder IUA) applications, are probably caused primarily by insufficient resolution of the terrain data and by the simplified procedure used in IUA for determining whether lin of sight exists. (The IUA side analysis seems to indicate that correction of these problems would enable IUA to produce results generally comparable to those of DYNTACS and CARMONETTE.)

c. With the exception of the IUA results on Site B, several general trends applicable to all three models emerged from these comparisons.

(1) When the typical defender weapon crew in a model searches a given 500-meter stretch of a likely enemy avenue of approach, the models and field experiment tend either to agree very closely or to disagree widely as to the amount of the path segment that can be seen. These two situations are equally likely, with each occurring in about 40 percent of the cases.

(2) In those cases where the models and field experiment do not agree, the models tend to indicate more intervisibility than the field experiment.

(3) The models are much more likely to agree with the field experiment when the field data indicate that either none or nearly all of the path segment can be seen from the defender position.

(4) All three models indicate that changes in weapon height have a much more pronounced effect on intervisibility levels than is indicated by the field data.

d. Additional similarities were identified between the DYNTACS and CARMONETTE model results. Both models indicate that the Hunter-Liggett sites are more open than was reported, and the two generally agree on the distribution of this increased intervisibility across the battlefield. Differences between the field data and both models also become more pronounced with increasing range.

e. Although no formal analysis comparing the three models to one another was prepared, the data used to compare the models to the field experiment are revealing (chapter 5). These data show that even though some similarities exist, the intervisibility results produced by each model are unique in several important respects. Even if the field data are ignored, no more than one of the models can possibly be accepted as accurately representing intervisibility at Hunter-Liggett because of the serious differences in the results produced by the models.

f. Generally, the degree to which DYNTACS results were found to be sensitive to the orientation of its terrain diagonals demonstrates what may be a widespread problem in terrain models--that intervisibility levels in the models are affected to a pronounced degree by arbitrary model parameters or inputs. The assignment of objective point locations in IUA is clearly a problem of this nature; the assignment of elevations to each CARMONETTE grid may also fall into this category.

8-4. INTERPRETATION OF DIFFERENCES. The fundamental issue underlying model verification is not whether differences between model and field experiment results exist, but what these differences mean in terms of the reliability of model results. As indicated in chapter 1, determining the reasons for the differences observed between model and field results and identifying the proper interpretations as to their significance are both beyond the scope of this initial report. At this point in the investigations, it can only be stated that there are four general sources from which these differences might stem:

a. The Models. The terrain models themselves could contain unsuitable procedures for evaluating intervisibility conditions, or errors could have been introduced in computerizing these procedures.

b. The Model Inputs. Errors could have been made in the interpretation of model input data requirements or in the actual preparation of these inputs. Alternatively, insufficient detail in describing the terrain area by inputs could be a factor.

c. The Field Experiment Data. As the field experiment relied heavily upon human beings as observers, controllers, data recorders, and data processors, there are a number of ways in which errors of various types might have crept into the field data used in these comparisons.

d. The Comparison Approach. Finally, the approach taken in performing these comparisons might have been inappropriate. Either the required levels of correlation implied in the approach taken may have been too demanding, or the approach may be based upon faulty interpretation of model or field results.

8-5. CONCLUSIONS. In light of these cautions on interpretation, only the following conclusions appear to be warranted at this stage of the investigations.

a. Major differences exist between the intervisibility levels and patterns produced by the three combat models and those reported by the intervisibility field experiments.

b. The general lack of close correlation between results from any two of the models seems to indicate a model problem of some complexity.

c. In light of the magnitude of the differences observed, it is clear that these differences must be resolved before proceeding to investigations of other battlefield activities that are contingent upon reasonable representation of intervisibility.

d. Resolution of these differences can only be accomplished through follow-on investigations into the four areas outlined in paragraph 8-4 above.

APPENDIX A

MODEL BIBLIOGRAPHY

APPENDIX A

MODEL BIBLIOGRAPHY

A-1. PURPOSE. This bibliography lists model documentation that was available during the TETAM Model Verification study. The bibliography is listed in annotated form as an aid to future users of the models. This bibliography is not necessarily an exhaustive list of models documentation, but the major sources that will probably be available to a user are included.

A-2. CONTENTS. The appendix is organized into three annexes, one each for DYNTACS, IUA, and CARMONETTE.

a. Annex I--DYNTACS. Documentation of DYNTACS is extensive, and the bibliography is close to being exhaustive. DYNTACS documentation is unique in that much of the early research that fed into the model development is documented as well as the model itself. Thus, this is the only model for which the basis of most of the model representations can, with sufficient research, be found.

b. Annex II--IUA. Documentation of IUA is best described as spotty. Adequate information exists only on the mechanics of operating the computer programs. No meaningful documentation of the basis for most of the model formulations has been found. Model logic flow is reasonably documented in flow chart form. No discussion of the ramifications of various input values is available; however, data bases that have been used are available. It appears that users may tend to use these bases without question.

c. Annex III--CARMONETTE. A set of CARMONETTE documentation has recently been produced. This provides a reasonable picture of gross model logic, some of the model algorithms, and the mechanics of program operation and data preparation. Some discussion of the ramifications of certain data items is also included. No documented basis for the formulations contained in CARMONETTE has been found. Older CARMONETTE documentation has not been included in the bibliography since none has been found that is not redundant with the current documentation.

ANNEX A--I

ANNOTATED BIBLIOGRAPHY FOR DYNTACS

1. EARLY REPORTS OF BACKGROUND RESEARCH AND PRELIMINARY MODEL CONCEPTS.

a. Bussman, Dale R. Vibrations of a Multiwheeled Vehicle. Ohio State University, TR64-1, August 1964.
Equations describing tank movement on a terrain surface are presented.

b. Howland, Daniel and Bonder, Seth. The Tank Weapon System. Ohio State University, AR63-1, June 1963.
Describes a general model to guide and integrate research in the related areas of tank mobility, firepower, and survival.

c. _____. The Tank Weapon System. Ohio State University, PR64-1, December 1963.
Research in the areas of soft soil ability and cross country mobility is presented. The effects of cant on the accuracy of the tank main gun are reported.

d. _____. The Tank Weapon System. Ohio State University, AR64-1, June 1964.
Tank mobility in soft soil or rough terrain is discussed. Development of the target acquisition and fire control models is described.

e. _____. The Tank Weapon System. Ohio State University, AR65-1, June 1965.
Separate computer models are described for firing, mobility, hit probabilities, lethality, acquisition, and armor distribution.

f. Perloff, William H. Tank Mobility in Soft Soils. Ohio State University, TF65-2, June 1965.
Describes a computer program for soft soil mobility analysis. Covers track slippage and tank sinkage.

2. INITIAL INTEGRATED MODEL.

a. Howland, Daniel and Clark, Gordon. The Tank Weapon System. Ohio State University, AR66-1, June 1966.
The DYNTACS model is first referenced in this manual. A model overview is presented and a detailed description of five modules, (1) terrain and environment, (2) tactical decision, (3) intelligence, (4) movement, and (5) firing, is included.

b. _____. The Tank Weapon System. Ohio State University, AR66-2, December, 1966.
Equations describing the probability of detection and time to detection between an observer and tank are presented. A field experiment to validate those equations is reported. Microterrain and power spectral density

as used in the ground play of line of sight are discussed in detail. Detailed descriptions of concealment input parameters PCCS and YMAX are included. Soil strength and limiting speeds for tanks are also discussed.

3. THE BASIC GROUND MODEL NOW RECOGNIZED AS DYNTACS.

a. Bishop, Albert and Clark, Gordon. The Tank Weapon System. Ohio State University, AR69-2A, October 1969.

The first of two principal analyst manuals for users of the DYNTACS manual. Although these volumes describe in detail only the early version of the model known as DYNTACS, documentation of subsequent changes, improvements, and additions to the model describe only those parts of the model actually changed. Thus, the model descriptions in these two analyst manuals apply except where changed by subsequent volumes. This volume contains detailed descriptions of the DYNTACS submodels developed to simulate (1) terrain and environment, (2) communications, (3) intelligence (i.e., target acquisition), and (4) movement control.

b. _____. The Tank Weapon System. Ohio State University, AR69-2B, September, 1969.

The second of two principal analyst manuals for users of DYNTACS. The remaining five modules comprising the DYNTACS model are described: (1) the fire controller, (2) the movement model, (3) the firing model, (4) the minefield model, and (5) the indirect fire ballistic weapon (i.e., artillery) model.

c. _____. The Tank Weapon System. Ohio State University, AR69-4, September 1969.

This volume is appended to the AR69 series to provide the reader an overview of this early research and its principal results. Perusal of this volume should provide an appreciation of the significance of the original methodology produced and a measure of its potential usefulness in the reader's area of involvement. It is essentially an executive summary of the early work.

d. Bishop, Albert and Stollmack, Stephen. The Tank Weapon System. Ohio State University, AR68-1, September 1968.

This volume is valuable for its development of the detection process still used in DYNTACS. Chapters covering concepts of visual detection, contrast-dependent detection, probability for stationary targets, target contrast, and analysis of detection time data are included. Other less important areas discussed are availability, reliability, rough terrain, limiting speed, and a methodology for predicting overall dimensions and gross weight.

e. Clark, Gordon and Moss, Leslie. The Tank Weapon System. Ohio State University, AR69-3A, June 1969.

This volume describes the design and use of the DYNTACS computer program. Included in this volume are subroutine descriptions and flow charts, detailed descriptions of the data used in DYNTACS, a description of how data are prepared for input to DYNTACS, instructions for running the program, and sample outputs. Due to the fact that DYNTACS is no longer run on the same computer and extensive modifications have been made to the ground game, this volume is now of little value to most users.

f. ______. The Tank Weapon System. Ohio State University, AR69-3B, June 1969.

This volume, a continuation of AR69-3A described above, is now of little value to most model users.

4. DYNCOM--THE FIRST MAJOR EXPANSION.

a. Bishop, Daniel and Clark, Gordon. The Land Combat Model (DYNCOM). Ohio State University, FR-1, June 1969.

This volume describes the design principles of the DYNCOM model. DYNCOM is a modification and extension of the DYNTACS model. This volume only describes modifications and extensions to the DYNTACS model; therefore, 69-2A and 69-2B must be read prior to this volume to get the complete description of the DYNCOM model. Major additions documented in this volume are artillery, crew-served weapons, and beam-rider missile modules. Associated modifications to movement and firing tactics are also presented as well as a significant reworking of the communications model. Additionally, research of some significance in modeling concealment, limited visibility conditions, and air/ground and ground/air visual detection are reported.

b. Clark, Gordon; Parry, Sam; Hutcherson, Don; Rheinfrank, John; and Petty, Gerald. Land Combat Model (DYNCOM) Programers Manual. Ohio State University, FR70-4A, April 1970.

This programers manual is a comprehensive list of input data commons, program descriptions, and flow charts of DYNCOM. Because FR70-4A and FR70-4B cover the complete model, it is not necessary to refer to earlier manuals. A cross reference listed in this manual between common areas and chapters which describe the model can be a valuable tool for preparing input data.

c. ______. Land Combat Model (DYNCOM) Programers Manual. Ohio State University, FR70-4B, April 1970.

This volume is a continuation of FR70-4A. The programers manual was broken into two volumes for ease of handling.

d. Clark, Gordon and Hutcherson, Don. Land Combat Model, The Aerial Platform Combat Operations Model. Ohio State University, FR71-3, May, 1971.

Documents the aerial platform module developed for DYNCOM. This module seems to have had limited acceptance, and the volume is not of great interest.

5. DYNTACS-X SECOND MAJOR EXPANSION.

a. Clark, Gordon and Parry, Samuel. Small Unit Combat Simulation (DYNTACS(X)) Counterbattery Fire Models. Ohio State University, FR70-1, July 1970.

The DYNTACS(X) version is an extension to the DYNCOM version. This volume reports the addition of a counterbattery fire module. As might be expected, it has no direct impact on the basic ground combat module.

b. Clark, Gordon et al. Small Unit Combat Simulation (DYNTACS(X) Air Defense Operations Model. Ohio State University, FR71-2A, March 1971.

As the title suggests, this volume documents inclusion of an air defense capability into the model. This differs from most other model expansions in that it could not be incorporated modularly but rather required extensive elaborations to the basic ground combat detection, firing, and fire control modules. A companion report (same authors, title, and date, issued as FR71-2B) contains flow charts and data layouts.

c. Clark, Gordon and Hutcherson, Don. Small Unit Combat Simulation (DYNTACS(X)) Fire Support Operation Models. Ohio State University, FR71-3A, October 1971.

This volume documents a revised aerial platform module, more accepted than the one developed for the DYNCOM version. The companion volume, FY71-3B, contains all flow charts and data blocks for DYNTACS(X).

ANNEX A--II

ANNOTATED BIBLIOGRAPHY FOR IUA

1. PREPARATION OF THE TERRAIN AND TACTICAL DATA BASE AND EXECUTION OF THE TERRAIN AND MOBILITY PROCESSORS.

a. US Army Combat Developments Command, Tank-Antitank and Assault Weapons Requirements Study, Phase III, Volume XIII, appendix III to annex L, AD849891L, December 1968.

The document contains the terrain and tactical analysis conducted during the TATAWS study for the IUA runs. It also provides several examples of the types of data needed to describe the terrain and the tactics played by attackers and defenders in the model.

b. ______, ______, Volume XXI, appendix VII to annex L, AD849897L, December 1968.

This report contains examples of the Red and Blue force compositions and tactical maneuvers for both forces used in the TATAWS runs. A complete listing of the critical range lines describing the model's tactical options for both attacker and defenders can also be found in the report.

2. DOCUMENTATION OF THE IUA COMBAT MODEL.

US Army Combat Developments Command, Tank-Antitank and Assault Weapons Requirements Study, Phase III, Volume XVIII, Tabs C and D of appendix V to annex L, AD849895L, December 1968.

The document contains flow diagrams of all programs and subroutines found in the IUA combat model. Flow diagrams of subroutines in the terrain and mobility models are not provided. Input card formats for the entire (terrain, mobility, and combat) data base are also provided.

3. GENERAL MODEL DOCUMENTATION.

a. US Army Combat Developments Command, Tank-Antitank and Assault Weapons, Phase III, Volume XVII, Tab B of appendix V to annex L, AD849894L, December 1968.

The document contains a table of all key model variable names and a description of their content. The variable names are grouped by subroutine for the terrain, mobility, combat, and postprocessor programs.

b. ______, ______, Volume XVI, Tab A of appendix V to annex L, AD849893L, December 1968.

The document contains a listing of all IUA programs. This includes the terrain processor, mobility processor, IUA combat model, output event processor, and the utility routines necessary to load the constant data deck.

c. Lockheed Missiles and Space Company, Instructions for Applying IUA Program to US Army CDC 3300, N-54-68-1, Sunnyvale, California, November 1968.

The document serves as an operator's manual, providing deck structures for exercising the model on the CDC 3300. The data base file structures used by the terrain processor, mobility processor, IUA combat model, and output event processor are also described.

d. US Army Combined Arms Combat Developments Activity, Procedure Guide for the Individual Unit Action (IUA) Model on the Fort Leavenworth Data Processing Installation CDC 6500 Computer System, Combat Operations Analysis Directorate Technical Report TR2-73, November 1973.

The document is an operator's manual, providing deck structure for exercising the model on the CDC 6500. It also contains a description of the input data card formats for the terrain processor, mobility processor, and IUA combat model.

4. DATA BASES FOR IUA COMBAT MODEL.

a. Goulet, B.N., Report on Support Provided by Army Material Systems Analysis Agency/Ballistic Research Laboratories for TATAWS III Computer Simulations (U), Army Material Systems Analysis Agency Technical Memorandum No. 20, Aberdeen Proving Ground, Maryland, January 1969, (SECRET).

Probabilities of hit and kill, and firing and flight times for weapons and rounds used in the TATAWS III IUA combat model runs can be found in this document. Much of the data is in the card format required by the IUA model.

b. Lockheed Missiles and Space Company, Report of Simulation Support for the Evaluation of Candidate Tank Considerations Using the Individual Unit Action (IUA) Simulation Model (U), LMSC-D009535, Sunnyvale, California, December 1972, CONFIDENTIAL.

The document contains probabilities of hit and kill for weapons and rounds used in the Tank Configuration study. Also included are distributions describing the time required by crews to detect a target. All data are in the format required by the IUA model.

ANNEX A--III

ANNOTATED BIBLIOGRAPHY FOR CARMONETTE

1. General Research Corporation, CARMONETTE, Volume I--General Description, McLean, Virginia, 1974.

This is an executive level overview of the model. It also contains, in the space of a dozen pages, the only available discussion of the mathematical basis of the model.

2. ______, CARMONETTE, Volume II--Data Preparation and Output Guide, McLean, Virginia, 1974.

This volume is oriented to the individuals responsible for developing CARMONETTE input data. Coding forms and instructions for preparing the data are included, with illustrative examples. Discussions of the ramifications of selected data items, many of which are of a subjective or aggregated nature, are also included.

3. ______, CARMONETTE, Volume III--Technical Documentation, McLean, Virginia, 1974.

This volume is programer oriented. It documents detailed logical flow, data layout within the computer, and mechanical operating procedures.

APPENDIX B

SENSITIVITY ANALYSIS OF COMPARISON VARIABLES

APPENDIX B

SENSITIVITY ANALYSIS OF COMPARISON VARIABLES

B-1. GENERAL. Intervisibility comparisons for TETAM depend upon the use of variables derived from the fundamental data collected in CDEC Experiment 11.8. These fundamental data are subject to some level of error, but a statistically sound means to measure the error inherent in the data is not known. Sensitivity testing was conducted to provide an indication of the probable stability of derived variables and, by implication, conclusions based upon such variables in light of the possible error in the fundamental data.

B-2. APPROACH.

a. Fundamental Data. The fundamental data from Experiment 11.8 of primary concern are the determined existence or lack of intervisibility from a viewing point in the field to an ATM target panel. In Experiment 11.8, such a determination was made from two observer heights at approximately 2,000 viewing points to each of 36 target panels for each of three trial conditions (termed Site A Rapid Approach, Site A Covered and Concealed Approach, and Site B). Based on the quality control procedures followed in the field, the CDEC final experimentation report states that "at the very worst, 5.0 percent of the data could be in error" (reference 1d, page A-1-13). Of secondary interest to this analysis is the reported nature of line-of-sight blockages. No direct quality control of the blockage data was attempted in the field experiment.

b. Derived Variables. The derived variables investigated in this analysis are, for each of the three trial conditions: the overall probability of line of sight, the number of intervisibility segments, and the mean length of an intervisibility segment. An intervisibility segment is the space between consecutive viewing points for which intervisibility to a single target exists. Intervisibility is assumed to continue without interruption between such viewing points. For segment length computations, a change of intervisibility status between two points is assumed to take place midway between the points. These variables, or trivial variations thereof, have been used by past studies including the CDEC analysis of Experiment 11.8 results in an attempt to describe terrain on the basis of a few descriptors.

c. Sensitivity Treatments. Four simplistic treatments, discussed below, were applied to the fundamental data for the purpose of viewing the sensitivity of the derived variables to changes in the fundamental data. Variations similar to those of the first two treatments might relect errors that actually took place in the field. Objectives analysis or error modes that actually occurred in the field would have to be based on the quality control data collected in the field which, unfortunately, were discarded in the field after serving their basic purpose.

(1) Random 5 percent treatment. For each "yes" and "no" determination of line-of-sight existence in the data base, a uniformly distributed random number on the unit interval was drawn and the determination changed if the random number exceeded 0.95. This is equivalent to changing 5 percent of the determinations, randomly selected.

(2) Selective 5 percent treatment. For each "no" determination in the data base, a uniform random number was drawn from the unit interval and the determination changed to "yes" if the random number exceeded 0.95. This is equivalent to changing 5 percent of the "no" determinations, randomly selected. Since the "no" determinations constitute 71 to 82 percent of the original data (depending on which trial condition is considered), this treatment changes 3.5 to 4 percent of the data. This may reflect field error to the extent that a missed determination is, from a subjective review of the experiment, the most likely error. There is, however, no basis for any quantified error rate or for applying such error randomly over the data.

(3) Flicker treatment. For this treatment, a line-of-sight segment is considered interrupted only if two or more consecutive determinations of no line of sight are made for a given ATM panel and approach path. Thus, isolated "no" determinations were changed to "yes" for this treatment. This is a highly selective treatment resulting in changes to well under 2 percent of the fundamental data. The treatment is intended to illustrate the critical nature of a selected, but small, portion of the data. It would be unduly pessimistic to imply that such a highly patterned error mode in fact took place in the field.

(4) No vegetation treatment. This treatment consisted of changing each "no" determination for which the nature of blockage was reported as being vegetation to a "yes" determination. This treatment amounts to a massive modification of the data base, resulting in changes to about one-third of the data for Site A conditions and 80 percent of the data for Site B. No such extreme error rate in the field data should be inferred. The threatment provides a comparison of the effects of a massive data change as opposed to the relatively small changes of the other treatments.

B-3. RESULTS OF THE ANALYSIS. The results of the sensitivity analysis are presented in tables B-1 to B-3 and are summarized below. Resulting derived variables are presented for the high-high and low-low combinations of target panel and observer height. Values of the derived variables for intermediate height combinations fall between the presented values, as would be expected.

a. Overall P_{LOS}. The overall probability of line of sight is relatively stable under all except the "no vegetation" treatment. This is to be expected from the nature of the treatments. Where less than 5 percent of the data are changed, it would be impossible for P_{LOS} to change by

Table B-1. Sensitivity Analysis, Site A Rapid Approach

	Number of Segments		Mean Segment Length (m)		Overall P_{LOS}	
	L*	H*	L*	H*	L*	H*
Original data	2961	2943	153	180	.25	.29
Random 5 percent treatment	5783	5801	86	95	.28	.31
Selective 5 percent treatment	5159	5104	100	113	.29	.32
Flicker treatment	2170	2163	221	254	.27	.30
No vegetation treatment	4553	4042	226	274	.57	.62

*L = Low observer and low target panel.
H = High observer and high target panel.

Table B-2. Sensitivity Analysis, Site A, Covered Approach

	Number of Segments		Mean Segment Length (m)		Overall P_{LOS}	
	L*	H*	L*	H*	L*	H*
Original data	2888	3155	136	145	.22	.25
Random 5 percent treatment	5750	6036	77	81	.25	.27
Selective 5 percent treatment	5333	5420	86	95	.26	.29
Flicker treatment	2115	2267	194	211	.23	.26
No vegetation treatment	5129	4818	217	248	.62	.67

*L = Low observer and low target panel.
H = High observer and high target panel.

Table B-3. Sensitivity Analysis, Site B

	Number of Segments L*	Number of Segments H*	Mean Segment Length (m) L*	Mean Segment Length (m) H*	Overall P_{LOS} L*	Overall P_{LOS} H*
Original data	2476	2807	89	92	.16	.18
Random 5 percent treatment	4759	5051	56	59	.19	.21
Selective 5 percent treatment	4566	4765	61	65	.20	.22
Flicker treatment	1697	1855	141	152	.17	.20
No vegetation treatment	585	528	2303	2569	.96	.97

*L = Low observer and low target panel.
H = High observer and high target panel.

more than 5 percentage points. In fact, for all except the random 5 percent treatment, the change in P_{LOS} Is a direct reflection of the amount of data changed by the treatment. For example, where P_{LOS} changes from 0.29 to 0.32 (selective 5 percent treatment, Site A Rapid Approach, high-high height combination) this is a direct indication that 3 percent of the data were changed to a "yes" determination. The effect of the "no vegetation" treatment on overall P_{LOS} is indicative of the degree to which vegetation played a role in the field determinations. For example, if the original data contain a P_{LOS} = 0.29 and the "no vegetation" results in P_{LOS} = 0.62 (Site A, Rapid Approach, high-high combination) it can be inferred that the remaining 38 percent of the data must contain landform blockages ("cultural" and "unknown" masks were rarely reported), and 0.62 - .29 = 0.33, or 33 percent of the blockage on the site is caused by vegetation; that is, the effects of vegetation and landform are approximately equal over the site. Vegetation clearly is the dominant factor on Site B.

b. Number of Segments. Both the random 5 percent and the selective 5 percent treatments produce a marked increase in the number of intervisibility segments. The trend was to be expected, since the data tend to appear in "strings" of intervisibility or nonintervisibility; and a random selection of changes to be made would tend to break up these strings. The extent of the change is noteworthy. Changes to at most 5 percent of the fundamental data increase the number of segments by at least 70 percent and, in some cases, essentially double the number of segments. The effect of the flicker treatment is totally predictable since each changed determination will connect two segments, resulting in a decrease of one segment. Thus, the decrease in number of segments indicates the exact number of changes made with this treatment.

c. Mean Segment Length. The effects of the various treatments on mean segment length are, in general, corollary to their effects on the number of segments. The marked increase in number of segments with the random 5 percent and selective 5 percent treatments indicates that both treatments are introducing a large number of isolated "yes" stakes, each of which would result in a 25-meter segment. Additionally, the 5 percent random treatment must be breaking up a number of segments into two shorter pieces. The net result of each of these must be to pull down mean segment length. Every change introduced with the flicker treatment, on the other hand, will join two original segments into one longer segment, pushing up the mean segment length.

B-4. DISCUSSION.

a. The most striking result of this analysis is the potentially extreme sensitivity of variables describing intervisibility segments to what would, in most field experiment situations, be considered an acceptable error rate. This extreme sensitivity appears to be related more strongly to the pattern, or lack of pattern, with which errors could appear in the data rather than to the actual number of errors. This point is further illustrated by the data in table B-4, in which the mean segment lengths for the Site A, Rapid Approach trial are shown for all height combinations under the flicker and no vegetation treatment. In this case, the flicker treatment involves a change to slightly over 1 percent of the data, while the no vegetation treatment involves a change to approximately one-third of the data. Considering this difference, the resulting mean segment lengths are remarkable similar.

Table B-4. Mean Segment Length (Meters) for Selected Treatments, Site A-Rapid Approach

Observer Height	Target Panel	Original Data	Flicker Treatment	No Vegetation Treatment
Low	Low	153	221	226
Low	Mid	158	226	230
Low	High	159	226	230
High	Low	166	241	267
High	Mid	173	249	273
High	High	180	254	274

b. It must be reemphasized that the extent and patterns of error actually present in the fundamental data collected in Experiment 11.8 are unknown and that there is no objective means to estimating this information, short of reexecution of the experiment. Thus, while this analysis provides an indication of the effect some hypothetical error patterns could have on the derived variables, actual error trends in the available data remain open to conjecture.

B-5. CONCLUSIONS.

a. Intervisibility segment descriptors can be highly sensitive to relatively low error rates within the fundamental data used to develop these descriptors.

b. The degree of sensitivity of intervisibility segment descriptors to errors in the fundamental data depends primarily on the patterns in which these errors may occur, not on the relative number of errors.

c. Probability of line-of-sight measures are not highly sensitive to moderate error rates in the fundamental data.

d. The degree of sensitivity of P_{LOS} measures to errors in the fundamental data depends upon the amount of error in the data. Error patterns are of relatively minor importance in determining this level of sensitivity.

APPENDIX C

PREPARATION OF FIELD DATA

APPENDIX C

PREPARATION OF FIELD DATA

C-1. GENERAL. During the early stages of the study it was envisioned that preparation of the field experiment data for the model comparisons would be a relatively straightforward undertaking requiring only the accomplishment of the following tasks: obtaining intervisibility data from CDEC in some suitable automated form; editing these automated data to eliminate the minor inconsistencies that sometimes accompany transmission of large amounts of data; finally, reformatting these data to facilitate their use with similar data produced by the three models. However, unexpected difficulties in obtaining these data in an automated form suitable for use on TRADOC Control Data Corporation 6500 computer at Fort Leavenworth and the discovery of a number of anomalies in the data provided by CDEC expanded this task into a sizeable undertaking. The purpose of this appendix is to describe the nature and extent of these problems and to describe the extent to which they were resolved.

C-2. DATA PROCUREMENT. The field experiment data were originally recorded on specially labeled and perforated "port-a-punch" cards issued to the collection teams in the field. These data were subsequently edited on a General Electric 605 computer at CDEC and were provided to the study team on a magnetic, card-image tape. A full description of the organization of this data file is contained in Volume V, CDEC Final Report on Experiment 11.8. The study team was unable to process on the TRADOC Control Data Corporation computer a series of intervisibility data tapes provided by CDEC during the period June to November 1973 due to apparent hardware incompatibility between the two computer systems. For this reason, a study team representative traveled to CDEC and obtained on punch cards the intervisibility data for the Hunter-Liggett sites. Shortly thereafter, the tape compatibility problem was solved. (It was traced to special file marks and blocking characteristics created by the GE 605 computer that required special handling on the Control Data Corporation computer.) Since work had already begun in editing and reformatting the punch card data by the time the tape problem was resolved, the card data were selected for use in the study.

C-3. DATA REFORMAT. A revision of the CDEC file structures and data formats was desirable for model verification for several reasons. First, it became obvious that a number of modifications to each model would be necessary in order to extract the detailed intervisibility data needed for evaluating model performance. Thus, it was necessary to establish a single, suitable format for model output data and to begin this model modification work at the earliest practicable date. Second, it was also obvious that, in the interest of quality assurance during model verification, data from the field experiment and the three models should be stored in a common format. The use of a common format for intervisibility data from all four sources would reduce the difficulties in editing these data and would provide for the use of a single set of computer

programs for the analysis and comparison of the several sets of data. Finally, it was determined that the format used by CDEC for storing intervisibility data was too highly compacted for use by the models. For these reasons, a new set of formats and a new file structure were developed and utilized. These are described in table C-1. During revision of the CDEC data structure, a number of anomalies in the field experiment data were discovered.

C-4. NATURE AND EXTENT OF DATA ANOMALIES. These data problems necessitated a series of manual and computer-assisted edits of the data originally obtained on punched cards. These edits resulted in the identification of a number of "illegal" data codes scattered through the data collected on both the experimentation sites at Hunter-Liggett. In an effort to resolve these inconsistencies in the punch card data, the study team examined the intervisibility data contained on the magnetic tape. Similar anomalies existed in the magnetic tape data, and there were also differences in the amount and content of data between the card and tape files. A summary of the nature and extent of these data anomalies follows.

a. CDEC Data Structure. A general knowledge of the organization of codes used for the field data is required in order to understand the data problems themselves. Intervisibility data provided to the study team by CDEC consisted of two sets of punched cards for each of the Hunter-Liggett site/tactic combinations. The first set, the LOS cards, consisted of one card for each stake and contained coded data indicating whether line of sight existed and, wherever appropriate, the reasons for nonexistence of line of sight from that stake to each of the 36 defender positions (panels) for each of 6 height combinations. The second set, the survey cards, contained the 10-digit UTM coordinates of each defender position and of selected stakes on each of the attacker routes. An example of an LOS card is shown at figure C-1. Card columns 9-44 and 45-80 on the LOS cards contain coded data describing the amount of each defender panel visible from that stake for the low and high attacker heights, respectively. In any one card column, the intervisibility conditions existing between a stake and a single defender weapon are specified by punches in the particular zones and rows of that column.

b. Legal Combinations. A complete list of the authorized punches and their meaning is shown in table C-1. Examination of these codes and their meanings indicates that only certain combinations of these punches should appear together in any one card column. The complete set of "legal" combinations of these row punches is contained in table C-2. All other combinations result in illegal combinations which are incomplete, ambiguous, or contradictory.

c. Illegal Code Combinations. Editing of the field data identified the presence of a number of illegal code combinations. These combinations generally fell into one of three categories, each of which is described below in order of increasing importance.

Table C-1. Intervisibility Codes for Field Data Cards

Card Zone Punch	Meaning
12	Can see top band only
11	Can see top two bands only
Ø	Can see all bands
None	No bands visible
Card Row Punch	
1	Not used
2	Terrain interrupts LOS
3	Vegetation interrupts LOS
4	Cultural feature interrupts LOS
5	Unknown reason for no LOS
6	Not used
7	Not used
8	Looking through trees (Site B only)
9	Not used
None	No given reason for interruption of LOS

Col: 123456789... 80

3301001ƀ232TL:·23 ...etc

Cols 1-2	Site
Cols 3-4	Path (trail)
Cols 5-7	Stake Number
Col 8	Blank
Cols 9-44	Visibility status of panels 1-36, respectively, as seen from the low observer position
Cols 45-80	Visibility status of panels 1-36, respectively, as seen from the high observer position

Figure C-1. Sample LOS Data Card

Table C-2. Legal Combinations of LOS Data Codes

Site A		Site B	
Zone-Row	Character	Zone-Row	Character
b̸ - b̸	Same as character to the left	b̸ - b̸	Same as character to the left
b̸ - 2	2	b̸-8-2	:
b̸ - 3	3	b̸-8-3	=
b̸ - 4	4	b̸-8-4	"
b̸ - 5	5	b̸-8-5	@
12-2	B	12-8-2	<
12-3	C	12-8-3	.
12-4	D	12-8-4	)
12-5	E	12-8-5	\
11-2	K	11-8-2	!
11-3	L	11-8-3	$
11-4	M	11-8-4	*
11-5	N	11-8-5	,
Ø - b̸	Ø	Ø-8	Y

(1) Incomplete code combinations. A problem existed when one punch in a column meant necessarily that another punch should appear but it in fact did not. For example, the presence of a 12-punch indicated that only the top color band is visible and implies that an additional punch should appear indicating the reason that the remaining bands could not be seen. Since only limited use was made of the recorded reasons for the nonexistence of LOS during the model work, the existence of errors of this type was not considered serious. However, they do indicate that on-site editing of field data may have been incomplete, or that the data compaction (or some other) process introduced errors to the data base.

(2) Contradictory code combinations. The second most frequently encountered type of data anomaly was the existence of two or more punches in a column that contradicted one another. One example of this type of error is a column containing the 0-3 punches. According to table C-1, this code means that all color bands could be seen but that vegetation obstructed vision to those bands which could not be seen--an obvious contradiction. This type error is particularly serious for two reasons. First, there is a real question as to whether LOS did or did not exist in these cases. Second, this type of problem occurred more than 600 times in the data for the HLMR sites.

(3) Blank column. The final and most critical problem was the existence of numerous blank columns in the LOS data. According to the CDEC data coding scheme, the absence of a zone punch (12, 11, or 0 punch) in any column indicated that none of the color bands could be seen and it should therefore be accompanied by an appropriate row punch. However, more than 100,000 blank columns existed in the HLMR data with no fewer than 32,000 of these occurring for any one site/tactic combination. During the attempt to resolve this problem, the study team was referred to Braddock, Dunn and McDonald Scientific Support Laboratory personnel who participated in the collection and subsequent processing of these data. BDM analysts indicated that under certain circumstances, the data collection teams were permitted to use blanks on the port-a-punch cards to indicate repetition of the first entry on each card. For example, in the case where line of sight was obstructed to all 36 panels by landform, the data recorder was instructed to record this information only for the first defender position and leave the rest of the columns blank. Subsequent examination of the patterns in which blanks appeared in the data showed this interpretation of blank columns to be reasonable in most instances but highly suspect in some. It is more likely that the many random occurrences of isolated blanks, or small groups of blanks scattered throughout the data, indicated missing data rather than efforts to improve the efficiency of data collection. In some cases, blanks were also discovered in the card columns corresponding to the first defender position. Again the existence of these problems indicated a possible data editing or compaction problem.

(4) Extent of code amonalies. A breakdown of the number of occurrences of illegal code combinations of each type is contained in table C-3. The amount of anomalous data found for the two tactics on Site A is less than 1 percent of the total data collected there, while the Site B data contained several times as many anomalies as were contained in the two sets of data for Site A.

d. Anomalies in Survey Data. In addition to the discrepancies in the LOS cards described above, anomalies were also found in the survey cards themselves and in attempting to match each survey card with its corresponding LOS card. These discrepancies were of three general types, each of which is described in succeeding subparagraphs. These anomalies are considered serious only insofar as they may indicate inadequate quality assurance primarily in editing the field data. Once these errors were discovered, the necessary corrective action became obvious.

(1) Redundant survey cards. More than one survey card existed for 32 stakes on Site B. In each case, the UTM coordinates contained on the redundant survey cards differed by several meters.

(2) Shifted fields. The 10-digit coordinates of the 36 defender weapon positions on both sides were found to be shifted one column to the left of their proper field, as they had erroneously been multiplied by a factor of 10. This problem occurred, in groups, on more than 280 of the stake survey cards for Site A (Covered Approach).

(3) Unpaired cards. Survey cards were found for which no corresponding LOS cards existed, and LOS cards were found at the end of a path for which no survey card existed. This situation provides LOS data for a point on the battlefield the location of which is not known.

e. Discrepancies Between Card and Tape Files. The intervisibility data on the magnetic tape were examined in an effort to resolve the anomalies discovered in the punch card data. This investigation disclosed that anomalies similar to those in the punch card data also existed in the magnetic tape data, that a number of differences existed between the tape and punch card files, and that the punch card file contained a considerable amount of data not included in the magnetic tape file.

C-5. CORRECTION OF DATA ANOMALIES. As each of the various types of data problems was discovered, an attempt was made to resolve it through discussions with appropriate personnel at CDEC. During this process, it became obvious to the study team and the CDEC analysts that some of these problems could not be resolved satisfactorily without a comprehensive and time-consuming review of the original field data. Because these data anomalies were found to be present in a relatively small percentage of the field data, it was decided that the study team should resolve these data problems as best it could and proceed with the model comparisons, being careful to avoid reliance on comparison methods

Table C-3. Summary of Illegal Characters in LOS Data File

Hollerith Character	Zone/Row Punch	Site A (Covered)	Site A (Rapid)	Site B
H	12-8	Ø	Ø	8
Q	11-8	Ø	Ø	12
S	Ø-2	52	23	Ø
T	Ø-3	127	53	376
U	Ø-4	Ø	Ø	1
V	Ø-5	5	9	Ø
8	8	Ø	Ø	65
+	12	5	2	54
-	11	34	34	54
,	Ø-8-3	Ø	Ø	3487
(	Ø-8-4	Ø	Ø	8
Random* Blanks	None	266	291	510
TOTALS		489	412	4576
% of Total LOS Data in Error		~ ½%	~ ½%	~ 4%

*Found in groups of less than 35 columns in a row.

overly sensitive to errors in the field data. The study team's approach to correcting these problems thus became one of attempting to identify and implement the most reasonable and logical interpretation of incomplete, ambiguous, or contradictory data in those cases where resolution based upon field experiment reality was not feasible. Specific corrections of each of the various types of data anomalies are outlined below.

a. LOS Data Corrections. In attempting to resolve problems in the actual line-of-sight data, greater weight was placed upon data describing whether LOS existed than was placed on data recording the reasons for nonexistence of LOS, for several reasons. First the collection of data describing the frequency and duration of LOS was the main objective of the field experiment. Second, quality control procedures implemented during the conduct of the field experiment were limited to checks on the accuracy of the "YES-NO" LOS data. Finally, for the purposes of evaluating model performance, only these fundamental LOS data were used to any great extent, since the data collected as to the reasons for nonexistence of LOS were the recorded judgments of the data collectors and no estimates as to the reliability of these data were possible. Thus, the greatest emphasis in attempting to resolve these data problems was placed on determining whether LOS existed, and these fundamental data were normally considered more reliable than other data where contradictions existed.

(1) Incomplete code combinations. In those cases where one or more of the color bands on a panel could not be seen but no reason was given for the nonexistence of LOS, the number of colors visible was accepted and the fact that no reason was recorded was ignored.

(2) Contradictory code combinations. Where the Ø-zone punch (entire panel visible) was accompanied by one or more row punches, the LOS data (zone punch) were assumed correct and the row punches ignored.

(3) Blank columns. Blank entries in the LOS data presented a special problem as many of these appeared to represent missing LOS data rather than abbreviated procedures for data collection. This matter was discussed with personnel at CDEC (HLMR) and their solution was to assume that the intervisibility status of the column immediately to the left pertained. The study team adopted this procedure because it was as good as any other for filling in what appeared to be, in many cases, missing data. It was recognized, however, that a simple decision rule cannot be expected to replace field experiment reality and that adoption of such a rule is done arbitrarily. (The study team considered the use of this procedure to be a matter of some concern until preliminary model results showed that differences between the models and the field experiment were much greater than differences that could be attributed to the use of this arbitrary rule.) In some cases, the leftmost column of a card was also blank, in which case the data on preceding and subsequent cards and for the other height combinations were manually reviewed and

a judgment made as to the most reasonable entry. The problem of leading blanks was encountered and resolved in this way about a dozen times in all.

. Survey Data Corrections. The types of anomalies found in the survey data were much less serious than those in the LOS data. The three general types of corrections made to the survey data are as follows:

(1) Redundant survey cards. The problem of extra survey cards was resolved by using the coordinates on the second card in sequence in all cases.

(2) Shifted fields on survey cards. These fields were shifted one decimal place to the right by machine. It appeared that some intermediate processing of the CDEC data had caused these shifts, but no attempt was made to discover just where the data shifts were introduced.

(3) Unpaired cards. Cards that did not have a corresponding LOS or survey card were removed from the data file by hand.

c. Discrepancies Between Card and Tape Files. Following the discovery that the punch card file contained considerably more data than the tape file, no further attempt was made to use the tape file data in resolving data anomalies and no attempt was made to correct anomalies in the tape file.

C-6. QUALITY ASSURANCE. During the process of preparing the field experiment data for use in the model comparisons, it became obvious that a check on the work performed was necessary in the interest of quality assurance. The complete revision of the intervisibility data structure, the correction of anomalies in these data, and the development at CACDA of a substantial amount of computer software for handling these data all were tasks which, if performed incorrectly, could have introduced errors into the baseline that would have been difficult to detect. Thus, it was decided that the accomplishment of one final task was necessary to insure that no errors had been introduced during the transformation and that the structure of the intervisibility data had not been altered by the correction of anomalies. The summaries of intervisibility data presented in Volume IV of CDEC final report on Experiment 11.8 and the CDEC computer program through which these summaries were derived provided the study team with the means for accomplishing these two objectives.

a. Initial Comparison. In an effort to verify the new data structure and the data handling and analysis software, the corrected data were processed by the CACDA software to produce summaries of these data similar to those presented in Volume IV of the CDEC final report. The procedures leading to these comparisons are shown in the schematic at figure C-2. A comparison of these summaries showed a number of differences between the

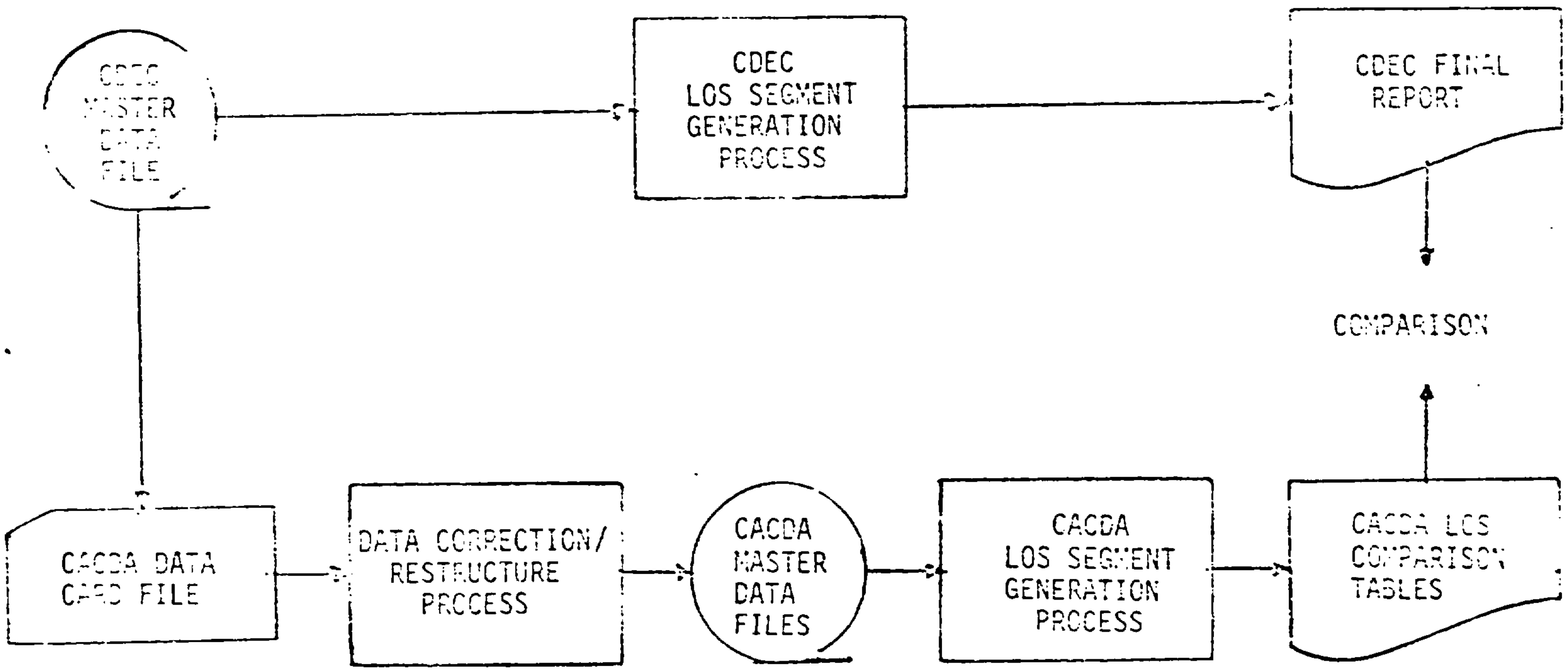

Figure C-2. Initial Quality Assurance Comparison

two in terms of both the number of line-of-sight segments and the distributions of segment lengths. These differences appeared to be relatively minor on Site A but were much more serious on Site B. It was not clear whether these differences should be attributed to differences between the corrected and uncorrected data or to differences between the CDEC and CACDA software.

b. Specific Actions. Two specific actions were initiated in an attempt to identify the source of these differences. A detailed review of the CACDA data handling and analysis software was performed, but this review merely verified that the newly developed procedures appeared to be sound. Therefore, a thorough review of the logic of the computer program provided by CDEC was undertaken. This investigation provided CACDA analysts with a better understanding of the way the various data anomalies were handled during the automated data processing operations that produced the CDEC final report and further indicated that differences observed could easily have resulted from the different treatments of data anomalies. For this reason, a more detailed investigation of the treatment of anomalous data appeared to be necessary.

c. Further Investigation. A series of alternative treatments of the data anomalies were investigated using various combinations of the corrected and uncorrected data sets and the CACDA and CDEC analysis programs. Because differences observed in Site B were much more pronounced than those for Site A, this investigation was confined to the Site B data. A summary for the numbers of line-of-sight segments produced by various treatment is shown at table C-4. The results of this investigation are summarized below:

(1) When the CACDA and CDEC analysis programs were used in conjunction with the corrected data set, they produced identical results. It was therefore concluded that differences in results produced by the two programs resulted from different treatments of the anomalous data and that the CACDA software was operating correctly.

(2) None of the various treatments successfully reproduced the presentations of results included in the CDEC final report. Moreover, each of the various treatments produced significantly more line-of-sight segments in most range bands than was reported by CDEC. The study team could not identify any treatment of the various data anomalies that could have produced as few LOS segments as reported by CDEC from the LOS data provided.

(3) It was concluded that the CACDA software, when used in conjunction with the corrected data set, produced LOS segment data that were at least as reliable as those available from the other sources and that no substantial improvement in this situation would occur prior to final resolution of the various data anomalies at CDEC. It was therefore decided that the corrected LOS data and CACDA software should be accepted as the baseline for model verification purposes.

Table C-4. Number of LOS Segments Generated for Site B Under Various Treatments of Field Data

Initiation Range Band (meters)	Observer Height	Panel Color	Data Treatment: Final Report FE 11.8	CDEC Program with Uncorrected Data	CDEC Program with Blanks Corrected	CDEC Program with Corrected Data	CACDA Program with Corrected Data	Preferred Interpretation of CDEC Data
0-1000	Low	Blue	1603	1650	1687	1689	1689	1622
		Red	1585	1641	1677	1679	1679	1614
		Yellow	--	1627	1670	1671	1671	1601
	High	Blue	1671	1775	1814	1816	1816	1754
		Red	1678	1792	1831	1833	1833	1771
		Yellow	1650	1778	1821	1822	1822	1759
1001-1500	Low	Blue	354	497	520	519	519	496
		Red	348	491	514	513	513	490
		Yellow	322	469	492	492	492	468
	High	Blue	371	536	547	545	545	530
		Red	362	531	543	541	541	525
		Yellow	333	512	522	521	521	506
1501-2000	Low	Blue	93	117	130	130	130	116
		Red	90	117	130	130	130	116
		Yellow	84	111	124	124	124	111
	High	Blue	132	150	177	177	177	159
		Red	129	159	176	176	176	158
		Yellow	117	148	165	165	165	147
2001-2500	Low	Blue	125	132	155	155	155	132
		Red	124	132	155	155	155	132
		Yellow	116	126	149	149	149	126
	High	Blue	152	178	201	201	201	178
		Red	148	176	199	199	199	176
		Yellow	135	173	196	196	196	173
2501-3000	Low	Blue	34	34	44	44	44	34
		Red	31	31	41	41	41	31
		Yellow	29	29	39	39	39	29
	High	Blue	49	55	64	64	64	55
		Red	51	57	66	66	66	57
		Yellow	47	57	66	66	66	57
3001+	Low	Blue	1	1	1	1	1	1
		Red	1	1	1	1	1	1
		Yellow	1	1	1	1	1	1
	High	Blue	4	4	4	4	4	4
		Red	4	4	4	4	4	4
		Yellow	3	3	3	3	3	3

C-7. SUMMARY OF PRINCIPAL FINDINGS. The principal findings and results of the work performed in preparing the field experiment data may be summarized as follows:

a. The intervisibility data provided to the study team contained anomalous data of various types. The study team, with the assistance of analysts at CDEC, identified and implemented corrections to these anomalous data which were, in many cases, based upon study team judgments as to most reasonable treatment. The extent to which these corrections reflect field experiment reality is unknown.

b. An examination of the effects on intervisibility of several alternative treatments of the various types of anomalous data was performed in order to insure that errors had not been introduced into the baseline during the process of revising the data structure and developing project software. It was concluded that the software developed by the study team was operating correctly and that the intervisibility data produced by this software using the corrected LOS data sets should be accepted as the baseline data for model verification purposes even though information derived from these data (e.g., number of LOS segments) was at variance with that presented in the final report on the field experiment.

APPENDIX D

IUA LOCATION DATA

APPENDIX D

IUA LOCATION DATA

D-1. GENERAL. In attempting to verify model intervisibility calculations, it was necessary to reproduce in the models the locations of 36 ATM target panels and the locations of approximately 200 viewing points on each of 10 approach routes for the three situations considered. Exact reproduction of approach route points was impractical for both IUA and CARMONETTE. Additionally, for IUA, reproduction of ATM panel locations was a moot issue since intervisibility calculations in IUA are carried out to objective points rather than to discrete defensive target positions. The treatment of these problems is discussed in this appendix.

D-2. SELECTION OF APPROACH ROUTES.

a. Problem. Given a set of approximately 200 UTM coordinates describing an approach route, it was necessary to select 30 or fewer points which, in some sense, provided a "best" representation of the route. (The maximum number of points accepted for direct input to IUA in describing one route is 30.) The resulting points were also used for CARMONETTE, which could not differentiate intervisibility differences between points in the same 100-meter square terrain cell. It was decided that the start and end points of each model route should correspond with those of the field routes and that the 30 model points should be a subset of the field points.

b. Selection Criterion. The criterion chosen to measure the fidelity of the model route to the actual route was the sum of squared deviations (SSD) of the field (surveyed) points from the model route. In this context, deviation was defined as the shortest distance from the field point to its corresponding line segment of the model route. Figure D-1 illustrates one segment of an IUA model route with several intermediate field points lying off the route. The sum of squared deviations (SSD) associated with this leg of the model route would be computed as follows:

$$SSD_{(123,127)} = \sum_{i=123}^{127} (dev_i)^2$$

$$= (0)^2 + (15)^2 + (5)^2 + (10)^2 + (0)^2$$

$$= 350 \text{ meters}^2$$

To determine the SSD for a proposed model path, this computation would be performed over the entire path.

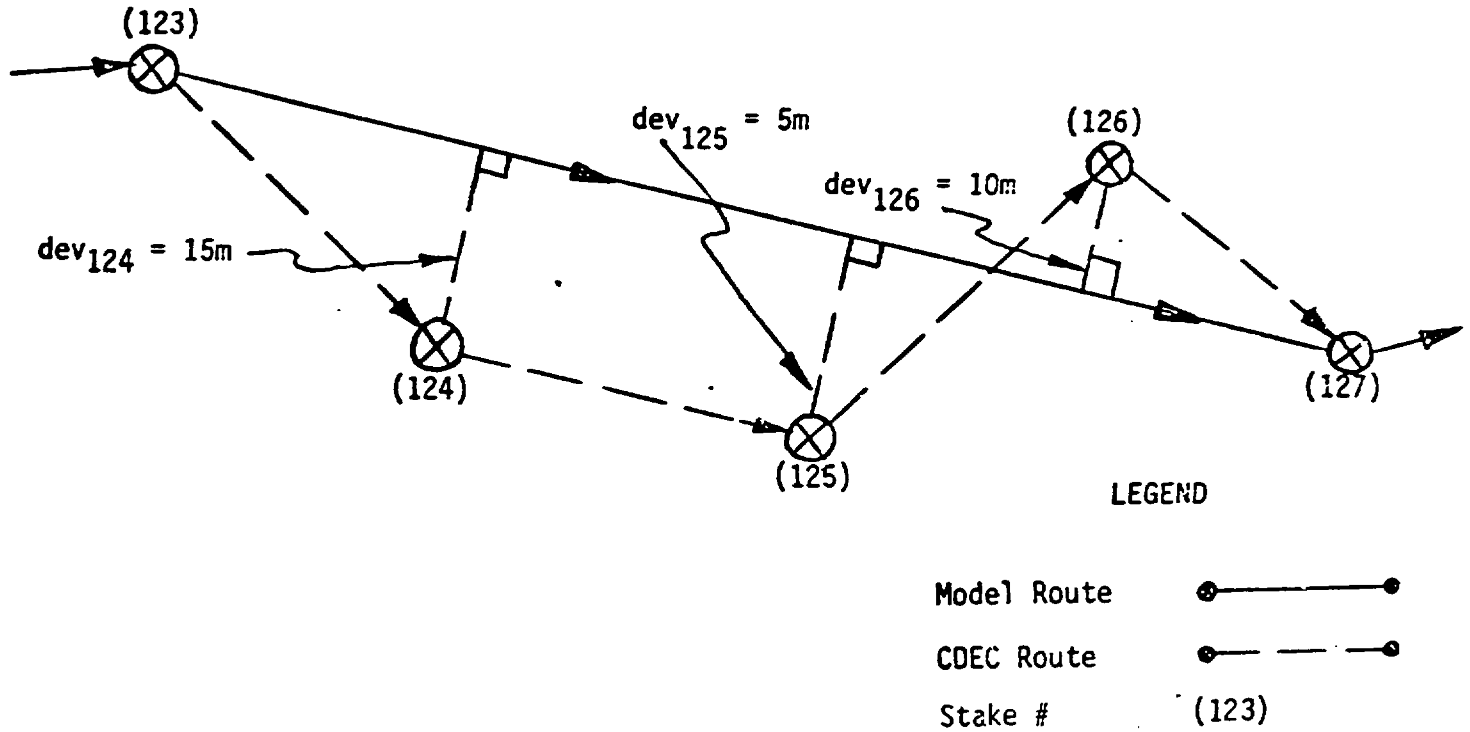

Figure D-1. Computation of Deviation Between Model and Field Routes

c. Selection Procedure. The problem then was to select 30 or fewer points from the field data points describing an optimal model path; i.e., one having the smallest SSD. A dynamic programing procedure was used to solve this problem. The algorithm starts at the beginning of the field route and moves, point to point, toward the end of the route. At each point an optimal model path segment is calculated from that point to the beginning of the field route. The optimal model segments are then used in the construction of an optimal model path along the entire route. As an example, consider field trail point 123 in figure D-1. The algorithm assumes that point 123 will be on the optimal model path. However, since the number of model points that will be selected for the final optimal path between point 123 and 1 is unknown, the SSD must be generated for all possible model segments. Table D-1 presents an abbreviated table of data generated to describe optimal model path segments from field point 123 to field point 1. From the table, it will be noted that segment 123 → 74 → 1 is the optimal three-point segment from 123 to 1 since it has the smallest SSD. This model path segment will be a part of any optimal path having a three-point segment between 123 and 1. After all optimal segments containing 4 points, 5 points, ... up to 29 points have been generated between point 123 and 1, the algorithm will move to point 124. Optimal segment calculations at this point are simplified by the use of optimal segments from the previous points. The algorithm continues until it reaches the final point of the field data. At this stage, it will have generated a set of optimal model paths over the entire field route containing from 2 to 30 points. The 30-point optimal path was selected as the IUA path simulating the field route. The extent of deviation of each of the 30 selected paths from the field data is shown at table D-2.

D-3. OBJECTIVE ASSIGNMENTS.

a. Problem. For intervisibility calculations, IUA requires that each defender position be associated with an attacker route objective point. Further routes may be grouped into up to three axes. Intervisibility calculations are actually made to objective points and the result applied to associated targets. Thus, it was necessary to define objective points and to assign each ATM position to an objective point.

b. Procedure. Route objective points were placed on the centers of mass of groups of panels that appeared, by map inspection, to be located near the end points of paths. This approach was consistent with the manner in which a user would be expected to select objective points based on IUA documentation. Axes were chosen by grouping together paths that were closely located. The maximum number of paths on any one axis was five. In most cases this axis selection is largely arbitrary since the paths are fairly evenly distributed across the terrain they traverse. Axis objective points were then placed on the centers of groups of panels associated with the particular axis. Coordinates of axis and route objective points and associated target panels are contained in table D-3.

Table D-1. Calculations for Optimal Model Path Segments From Field Points 123 and 124 to Field Point 1

Field Trail Points	Number of Points in Model Path Segment	SSD	Model Segment
123	2	1035*	123 → 1
	3	528	123 → 122 → 1
	3	725	123 → 121 → 1
	⋮	⋮	⋮
	3	175	123 → 75 → 1
	3	170*	123 → 74 → 1
	⋮	⋮	⋮
	4	520	123 → 122 → 121 → 1
	4	515	123 → 122 → 119 → 1
	⋮		
	29	428	123 → 122 ...
124	2	1105	124 → 1
	3	1035	124 → 123 → 1
	3	1049	124 → 122 → 1
	⋮	⋮	⋮
	4	170*	124 → 123 → 74 → 1
	4	280	124 → 122 → 121 → 1
	⋮	⋮	⋮

* Indicates optimal path segment

Table D-2. Deviation of IUA Paths from Field Experiment Routes

		Site A Rapid Approach		Site A Covered Approach		Site B Rapid Approach	
		SSD (Meters^2)	Mean Dev (Meters)	SSD (Meters^2)	Mean Dev (Meters)	SSD (Meters^2)	Mean Dev (Meters)
ATTACKER PATH	1	1969	3.12	1912	3.28	923	2.35
	2	672	1.93	1721	3.12	1004	2.37
	3	2033	3.27	1965	3.38	1374	2.75
	4	849	2.06	1552	2.74	355	1.42
	5	1551	2.72	2180	3.27	743	2.12
	6	800	2.00	932	2.20	563	1.85
	7	2066	3.14	2666	3.51	345	1.52
	8	1018	2.37	4473	4.42	471	1.76
	9	1702	2.82	4267	4.31	100	.87
	10	1110	2.28	3745	4.04	475	1.76

Table D-3. Objective Points and Panel Groupings

Site (Tactic)	Axis Number - Objective Point	Route Number - Objective Point	Defender Panels Assigned
ALPHA (Rapid)	#1 - 55697788	1 - 55517773 2 - 55367798 3 - 55867780	(4), (5) (1), (3), (6), (7), Y, Z S, U, X, Y
	#2 - 56407790	4 - 56197807 5 - 56337773 6 - 56547766 7 - 56467803	T P, Q, R, D, E, G, H, J, K, M L
	#3 - 56907785	8 - 56747770 9 - 56777791 10 - 57207773	6, A, B 5, 7, 8, 9, L 1, 2, 3, 4
ALPHA (Covered)	#1 - 55707770	1 - 55517773 2 - 55647790	(4), (5) (1), (2), (6), (7), S, V W, X, Y, Z
	#2 - 56567767	3 - 55937812 4 - 56427771 5 - 56567767 6 - 56737791 7 - 56717785	T G, H, J, P, Q, R D, E K, M A, B, C, L
	#3 - 57007760	8 - 56777792 9 - 56917780 10 - 57207773	8, 9 5, 6, 7 1, 2, 3, 4
BRAVO (Rapid)	#1 - 5[illegible]488222	1 - 52438232 2 - 52178214	S, T, U, W, X, Y, Z R
	#2 - 52188178	3 - 52088202 4 - 52018201 5 - 51978197 6 - 51908179 7 - 51908172	Q, (1), (2), (4) P, (5), (6) (7), J, K, L, M E, G, H A, B, C, D, 6
	#3 - 52118124	8 - 51708167 9 - 52118121 10 - 51398158	7, 9 1, 2, 3, 4, 5 8

APPENDIX E

LESSONS LEARNED

APPENDIX E

LESSONS LEARNED

E-1. GENERAL. In performing the work described in this report, the study team learned a number of lessons related to the preparation, application, and validation of the three models. These lessons are included here in the hopes that their reporting might in some way benefit current and prospective model users and their work. These lessons fall generally into two categories: those general lessons that might benefit study team leaders, study managers, and other decision makers and those lessons in the details of model preparation, operation, and maintenance that might assist model teams in preparing and running these models in the future.

E-2. LESSONS IN MODEL PREPARATION. The principal lessons of general interest in preparing the three models for an application are related to the preparation of terrain data.

a. Requirement for Real World Terrain. There are no two general schools of thought on the requirement for having in the models terrain data that accurately describe specific real world terrain sites (likely battlefields) as opposed to terrain data describing nonexistent but ostensibly representative (theoretical) terrain. Both schools were represented on the study team, and disagreement as to whether there actually is a requirement for the preparation of highly accurate real world terrain data for normal applications was not resolved. However, on the presumption that specific model applications exist for which theoretical terrain is not suitable, and in view of the fact that current model application practices assume that terrain data bases are developed for general (i.e., not scenario specific) applications and these data are therefore used time and again, then several observations concerning preparation of terrain data are in order.

b. Level of Effort. The preparation of highly accurate terrain data for these models is a laborious and time consuming task. The general impression persists that DYNTACS uses "digitized terrain" and that the preparation of DYNTACS terrain data is not the major undertaking that it is for the other two models. Digitized elevation data are used in DYNTACS but all other terrain inputs (of which there are a considerable number) are prepared by hand. About 2 man-months are required to prepare terrain by personnel possessing a reasonable understanding of how these data are to be used in the model and possessing the ability to read both military mapsheets and aerial photographs with facility.

c. Lead Time. The data required for preparation of highly accurate terrain inputs include military mapsheets, aerial photographs, digitized elevation tapes (essential for DYNTACS, useful for CARMONETTE) and soil, terrain roughness, and vegetation overlays. In addition one or more on-site inspections of the actual terrain is desirable during the preparation

process. With (normally) the single exception of military mapsheets, the procurement of all of these items requires considerable lead time so model applications requiring terrain data preparation must be planned for several months in advance. It may be worth noting that mapsheets of a scale large enough for extracting elevations and their locations by hand (1/25,000 or larger) are becoming increasing difficult to obtain.

d. Accuracy of Elevation Data. The accuracy of elevations used in calculations during a typical model run is determined by the accuracy of the sources from which terrain inputs are prepared, the accuracy inherent in the procedures for preparing data from these sources for model use, and the accuracy inherent in the methodology for selecting and applying these data in model computations.

(1) Accuracy of source data. In contrast to a preconception held by the study team, the team learned that digitized elevation data are normally developed from standard Army mapsheets with elevation data between contour intervals derived through interpolation. Thus, the major differences in accuracy between digitized and hand-prepared elevations derive solely from differences in the accuracy with which these data are extracted from the mapsheets and the accuracy of the respective interpolation methods.

(2) Processing accuracy. The accuracy with which these source data are prepared for use in the models is also important. Both IUA and CARMONETTE introduce human error and subjectivity into this process, and the procedures for these two models can introduce actual mistakes into the data as well as minor variations. DYNTACS, on the other hand, provides for the automated preparation of these data, thus eliminating most subjectivity and human error from the process. It appears, however, that in this case the cure can be worse than the disease. In a typical DYNTACS application, the preparation of elevation data can involve a sequence of up to three major adjustments through interpolation to the entire elevation data base (reference 7). While two of these interpolations can be avoided entirely (provided that the user is aware of the problem) and the third (and probably least serious) interpolation could also be eliminated at some cost, nowhere in the model literature is the model user warned of this problem. Potentially, the error introduced in the automated processing of elevations for DYNTACS could be much worse than those for the other two models.

e. Quality Assurance. Suitable procedures for verifying the accuracy of terrain inputs exist only for the DYNTACS model. While mistakes made in extracting, recording, or keypunching terrain data are likely to go undetected in IUA and CARMONETTE, a number of computer programs have been developed for DYNTACS that produce graphic representations (contour maps, shaded vegetation areas, etc) of the terrain inputs, and these graphics make the detection of most types of major errors highly likely. The US Army Concepts Analysis Agency has recently completed work on adapting some of these verification procedures for use with CARMONETTE.

E-3. LESSONS IN MODEL APPLICATION. Three specific lessons related to application of the three models are notable.

a. General Purpose Terrain. Even though the intention may have been to develop terrain data bases of general usefulness, terrain data bases have in the past typically been developed for particular model applications. Because of the effort required in developing data for new terrain areas, these terrain data have been used in one model application after another. The importance of these two observations taken together is illustrated by the fact that, in all three models, line of sight cannot exist to weapons located in certain types of vegetation even though these weapons may be antitank missile weapons emplaced specifically for long range observation and fires. In order to avoid this obvious mistake, the preparer of terrain data must know during data preparation the general area in which these weapons are to be emplaced. Thus, the concept of general purpose terrain data bases is somewhat misleading. In every model application, terrain data must be carefully reviewed, by knowledgeable model experts, to determine whether revisions to these data are required by the scenario to be played (with particular emphasis on defensive areas).

b. Model Scenario Development. During the intervisibility study it was learned that establishing defender weapon locations in the models by (mathematically) converting UTM coordinates to model coordinates often did not produce results desirable for model applications. In some cases, the geometric model representations of terrain surface and vegetation precluded model weapons from realizing the good observation and fields of fire enjoyed by their field experiment counterparts. This can often be corrected by changing slightly the location of defender weapons in the models. A computer program is available for DYNTACS that computes and displays all areas of the battlefield that can be observed from a specific defender (or any other) location. Both IUA and CARMONETTE also provide some information on LOS. The lesson is, of course, that some capability exists within each model to check the amounts of intervisibility produced for specific battlefield locations and these capabilities should be exercised so that weapon locations in the models are established based upon the extent to which their desired intervisibility characteristics are actually achieved. However, one cannot escape the observation that in doing so, the model user makes the final determination of the amount of intervisibility to be achieved from each position. Whether the models can be used as predictive tools in determining overall visibility levels from individual positions thus remains an open question.

E-4. LESSONS IN MODEL VERIFICATION. Two principal lessons in model verification stand out.

a. Resources Required As expected, the work described in this report absorbed the considerable technical resources shown in table E-1. These figures include 40 man-weeks support provided by the Concepts Analysis Agency.

Table E-1. Professional Manpower Expenditures (Man-Weeks)

Major Task	Qualification: OR Analyst	Computer Specialist	All
Approach Formulation	10	--	10
Baseline Definition	28	35	63
Methodology Development	29	14	43
Model Preparation/ Operation	71	73	144
Comparison Analysis	30	12	42
All Tasks	168	134	302

b. Simultaneity of Experimentation. An ideal situation for purposes of model validation would be simultaneous exercise of the model and field experimentation. This would permit discrepancies between the field and the model to be fully understood, explored, and, hopefully, resolved by return to the field and in-depth study as required. Such an approach would require commitment of experimental resources to a flexible schedule paced by the validation.

5. SUMMARY. A number of useful lessons related to preparation, application, and verification of the three models were identified during the conduct of this work. Those believed to be of general interest have been reported.

APPENDIX F

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REPORT DOCUMENTATION PAGE — READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: TR-4-76 (14) CACDA-TR-4-76

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle): (6) TETAM Model Verification Study. Volume I, Representation of Intervisibility, Initial Comparisons.

5. TYPE OF REPORT & PERIOD COVERED: (9) Final rept.

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s): (10) [redacted] Allan R./Christensen, [redacted] John R./Statz, Jr., [redacted] David K./Hugus, [redacted] Roger L./Burroughs [redacted] James F./Fox, Mr John E. Gahan, ~~Mr Ross A. Wells~~

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS: Directorate of Combat Operations Analysis (ATCA-CA) US Army Combined Arms Combat Developments Activity Fort Leavenworth, Kansas 66027

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: ACN 21646

11. CONTROLLING OFFICE NAME AND ADDRESS: Commander (ATCG) US Army Training and Doctrine Command Fort Monroe, Virginia 23351

12. REPORT DATE: (11) Feb[redacted]1976

13. NUMBER OF PAGES: 161

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): (12) 15?p.

15. SECURITY CLASS. (of this report): Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

Vol 2 - A024 168

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Combat model, combat simulation, field experiment, antitank warfare, intervisibility, line of sight, antitank missile, terrain analysis, tactical effectiveness, IUA model, DYNTACS model CARMONETTE model, detection, target acquisition

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The TETAM Model Verification study is reported in three volumes describing the validation of three high resolution combat simulation models (DYNTACS, IUA, and CARMONETTE) using field data collected by US Army Combat Developments Experimentation Command during Experiment 11.8. Volumes I and II contain an intervisibility study describing the abilities of the DYNTACS, IUA, and CARMONETTE terrain processors to predict line-of-sight occurrences between tanks and antitank missile positions. Volume III contains a validation study of

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

0 082

20. the engagement processors of DYNTACS and IUA. The results from the simulation models in terms of firings, engagements, and losses between tank and antitank as compared with the field data collected during the free play battles of Field Experiment 11.8 are found in Volume III.